Economic Study of Assurance of Supply Requirements for Water Resource Management with Reference to Irrigation Agriculture

Volume 1
Final Report

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EXECUTIVE SUMMARY

All natural water resources, including dams, form part of hydrological systems. Every system has a certain water yield during a specified time period. This yield is influenced by stochastic processes such as rainfall, evaporation, seepage, infiltration, vegetation, droughts, floods and demands from the various water-use sectors. The water demands within a hydrological system are dynamic and are based on population growth and economic development. The purpose of water resource planning is to determine the sustainability of the available water supply with current and growing demands imposed on the system.

The system yield can be determined by performing a yield analysis, which is initially based on historical sequences, and thereafter on stochastic sequences. The historical firm yield (HFY) is determined from historical observed flow sequences in the system and the system's ability to constantly supply the required demand at the current development level without failing. Since historical records are seldom repeated, it is important to predict what the sequences are likely to be in future; therefore, stochastic sequences are generated. The variability of system yield behaviour can be evaluated by observing the performance of a water supply system using many long- and short-term sequences with defined operating rules. The water supply system's yield reliability cannot be assessed accurately without generating simulated sequences based on historically observed sequences. Computer-based models are used for these analyses.

Water is a limited natural resource. The natural distribution and variability of water are not sufficient to meet the needs of all users at all times. This emphasises the need for water allocation as a means of facilitating sharing between different regions and competing users. Consideration should be given to prioritising water consumers according to the economic value of the products produced with the available water within the system. The difficult task of the water resource manager is to prevent a total system failure by deciding whom to curtail and by how much. Such a decision can be supported by determining the economic benefit of the products produced for the specific region of supply or catchment.

For the past 25 years, analysis for drought management has been carried out with various models, and a distinction was made between different priorities and associated risk levels in terms of water supply to users in drought conditions. This research focuses on applying quantitative economic analysis to improve on the status quo in terms of risk-based water-restriction analysis. The driver behind stochastic risk and water-restriction analysis is the priority classification of the different water-use sectors. The definition of the priority classification or criteria for risk of curtailments has largely been based on expert opinion and qualitative economic criteria. The aim of this study is to develop a methodology for deriving an effective priority classification, in terms of the economy, for drought management and scheduling of augmentation requirements.

The study approach entails analysing the effect on macroeconomic indicators – such as gross domestic product (GDP), employment creation and low household income – by allocating different levels of assurance of water supply to the various water user sectors within selected economic regions. These sectors include irrigation agriculture, urban, mining and industrial users. The methodology identified to realise the study approach involves creating a link between the existing water resource planning model (WRPM) and the water impact model (WIM) such that the economically best user priority classification can be derived. The models are linked by means of post-processing using Excel™ Visual Basic. Such an integration could serve as platform that offers decision-making support in terms of assurance of supply requirements based on a quantitative (scientifically grounded) method as opposed to the current qualitative assessment.

The water resource yield model (WRYM) is used to determine the HFY, and the short- and long-term capacity of a specific resource. The WRPM uses both stochastic sequences and short-term yield capacity to predict probable future yield. The probability of a system failure within a certain time period can therefore be calculated. The risk of failure or its inverse – the assurance of supply – is determined, which enables proactive interventions during times of drought. Assurance of supply forms the basis of sustainable water resource management.

The WIM was developed to determine the impact of reduced water supply on the crop yield of irrigation crops, and subsequently the economic indicators of the region. The crop data, namely, water volumes, hectares and specific crop production budget are the main drivers of the WIM whereby the macro-economic indicators are estimated. Economic multipliers as derived from the social accounting matrix (SAM) model and the Leontief inverse applied are used in the WIM to calculate direct and indirect impacts.

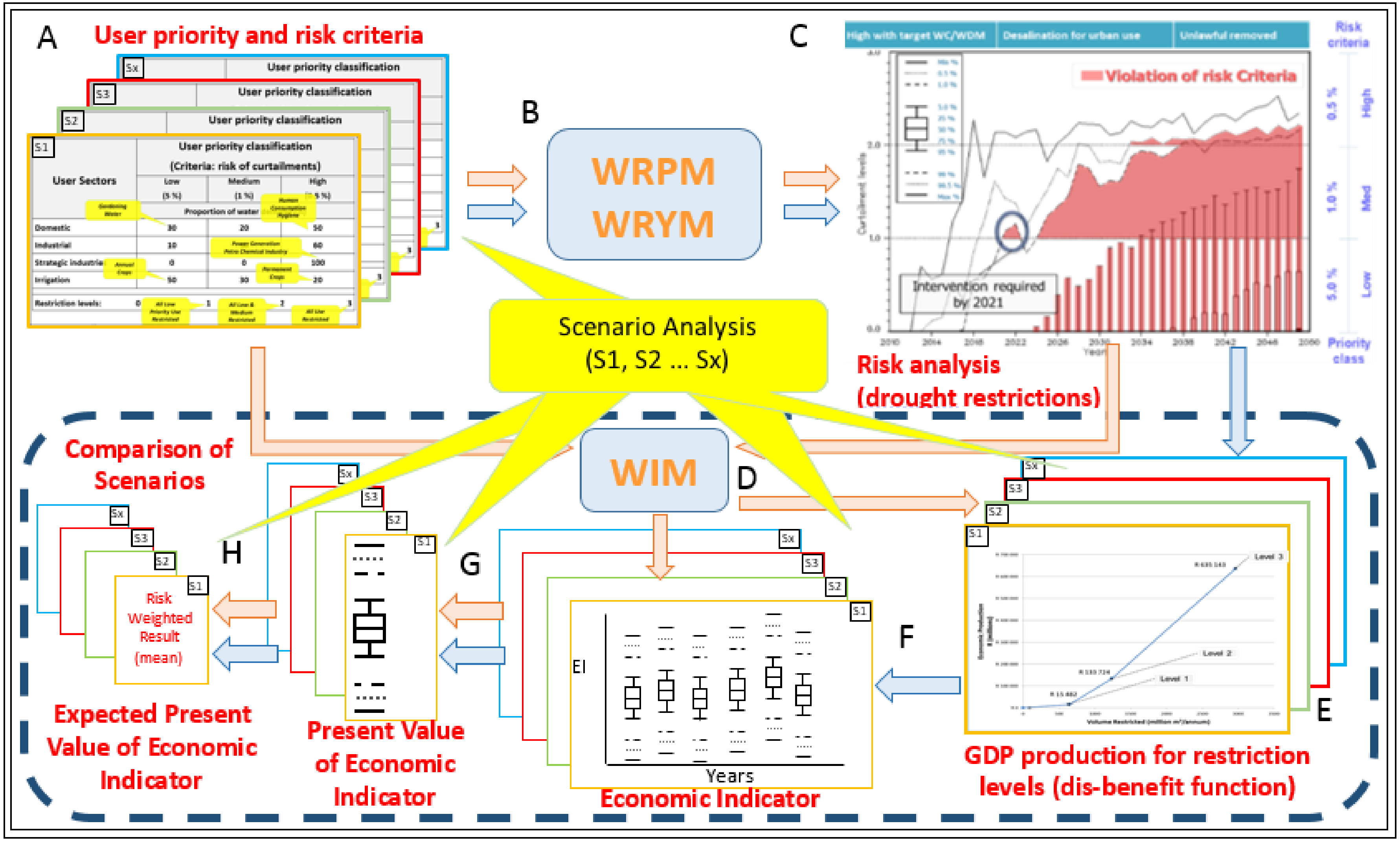
The focus of the study is therefore on the irrigation agriculture sector; however, any amendments to the assurance of supply to one user sector affect the assurance of supply to another. Crop detail and varying assurance of supply levels are incorporated in the WRPM to determine the available supply for a given scenario. For the irrigation agriculture sector, the economic impact on crop yields as a result of non-supply at different crop growth stages is envisaged. Water supply assurance affects the WIM and its resulting indicators by crop yield variation. The variation leads to a new macroeconomic impact for the region supplied by the water resource.

Based on the outcome and interpretation of the analyses, criteria can be developed to allocate assurance of supply, which serve as guidelines for water resource managers for a more informed decision-making process to allocate water equitably.

The ability of a system to supply water at various reliability indices is derived from the short-term yield characteristic curve of the system. With the aid of probabilistic techniques, different possible drought scenarios can be simulated. Up to a 1000 sequences are simulated in the WRPM for a single year, which results in a 1000 different probabilities to reduce water supply. The WIM makes provision to automate the process of incorporating the results from the WRYM/WRPM instead of inputting manually. The WIM then produces an annual time series of economic indicators (GDP, employment and household income). The output of the 1000 simulated sequences are presented graphically as probability distribution plots (box plots) for inspection and comparison among the scenarios analysed.

The main objective is to find the present value at various discount rates for each economic indicator within an economic region, which is influenced by a change in water supply. Based on the interpretation of the present values, a decision can be made in terms of the risk criteria to be configured in the WRPM for the specific economic region.

By comparing the results from the developed scenarios, additional scenario options could be derived for further analyses. This derivation is aimed at making provision for extreme water resource system yields, resulting from the specific decision of the user priority or risk of curtailment criteria. Sensitivity analyses will ultimately consist of an iterative process between extremes of which the most favourable results can be determined by reviewing the present value for different economic indicators for the selected economic regions. The results as per present value for each economic indicator are presented as box-and-whisker plot. The proposed methodology is illustrated in the figure that follows.


A
User priority and risk criteria
User priority classification
(Criteria: risk of curtailments)
User Sectors
Domestic
Industrial
Strategic industries
Irrigation
Restriction levels:
B
WRPM
WRYM
C
High with target WC/WDM
Desalination for urban use
Unlawful removed
Risk criteria
Violation of risk Criteria
Intervention required by 2021
Priority class
High
Med
Low
Risk analysis (drought restrictions)
Scenario Analysis (S1, S2 ... Sx)
WIM
D
E
F
G
H
Comparison of Scenarios
Risk Weighted Result (mean)
Expected Present Value of Economic Indicator
Present Value of Economic Indicator
EI
Years
Economic Indicator
GDP production for restriction levels (dis-benefit function)

The steps from A to H (see previous figure) are summarised as follows:

- The user priority and risk criteria (A) are the main variables as input to the WRPM for the scenario analyses to be undertaken. The user priority and risk criteria do not apply to the WRYM. The system yield and the demand imposed on the system indicate if there are any deficits, which is referred to as a proportion of non-supply.
- A risk analysis is undertaken with the WRPM (B). The output file represents simulated curtailment levels for the water supply system (C).
- These curtailment levels are factors converted to a proportion of the original full water supply and imported to the WIM (D).
- The impact of a reduction in water supply on the economic indicators is determined with the WIM for each of the simulated levels of curtailment. A disbenefit function can be derived for the relationship between the value of the economic indicator and the volume of the restriction level (E).
- A probability distribution for the simulated values of the economic indicator (F) is expressed over time.
- The present value for each of the simulated values of the economic indicator is calculated based on a selected discount rate (G).
- The mean value of the simulated present values is determined to present a single risk-weighted result, which can be compared among the various scenarios (H).

Three different irrigation regions were selected in South Africa as case studies to test the integrated assurance of supply model (ASM). These include the Orange River System, the Groot Letaba River System and the Mhlathuze River System due to the diversity of irrigation farming, geography and crop type. These systems are also referred to as economic regions. Water resources, irrigation and economic data are readily available for the selected study areas. System analyses for these systems were executed where the yields of the systems at different storage levels were determined by the WRYM. Results from these analyses, referred to as short-term curve yield characteristics, were incorporated into the allocation procedure/component of the WRPM.

The scenarios identified to be analysed for the Orange River System were adopted from the Orange River Annual Operating Analysis 2016/2017 planning scenarios. The same user priority classification was used for all the scenarios. Two alternative options in terms of the user priority classification were presented and discussed at the *Third Study Steering Committee Meeting for the Development of Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River in November 2013*. The interpretation of the results for the alternative user priority options conceded that a lower assurance of water supply leads to a larger volume of water that can be supplied but with less protection of the system or source during extreme dry periods. Neither of these user priority options have been used in previous analyses and were included in the sensitivity analyses undertaken in this study.

The water balance from the study named *Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System* indicated that a positive water balance could only be achieved up to 2030. The WRPM analysis results showed a reduction in the assurance of supply from about 2033/2034 onwards. Recommendations from the study suggested that further refinement of the priority classification could also contribute to an improved water supply. For the Groot Letaba River System, the HFY from the system is far less than the demand imposed on the system. Therefore, supply to the current users was evaluated with the existing operating rule in place. Scenario Lii from this study was used to test the methodology in the Groot Letaba River System.

In the Mhlathuze River System, findings from the study titled *Modelling Support for Licensing Scenarios* recommended that additional sensitivity analyses be carried out to evaluate the effect of alternative assurance of supply criteria on the allocation balance (resulting water-use entitlements). The analysis results from that study indicated that minor changes in the criteria could have a substantial impact on the results, which therefore warranted further investigations. For the Mhlathuze Water Supply System, a scenario entailing a reduced allocation to the urban (10%) and irrigation sectors (40%) was used as point of departure for sensitivity analyses to be undertaken.

The alternative user priority settings were analysed to find the optimum or most suitable set of parameters as input to the WRPM. Even though the analyses and decision support tool focused on the irrigation sector, the alternative user priority risk criteria options could result in changes in water supply to other water user sectors as well. Some options also include changes in the proportional water allocation to other user sectors. This means that although alternative user priority classification settings result in more positive economic outcomes for the irrigation sector, water supply to other user sectors may need to be curtailed earlier and more severely. This could result in detrimental economic impacts.

A relationship between the loss per economic indicator and the volume of water supply curtailment was generated for each of the scenarios analysed in the Orange River System. This relationship curve serves as a tool excluding the iteration process in the WIM. Thus, such a relationship curve is adopted for a specific water supply system once the optimum relationship curve has been derived from the scenario analyses and iterations. The relationship curve was created by plotting all 1000 simulated sequences per year analysed for each economic indicator against the same year's 1000 sequences of the curtailed volume. The relationship curves for all these years analysed in the Orange River System had a similar slope, and a single relationship per scenario was derived. When the relationship curves of the different scenarios in terms of the loss in GDP, loss in employment and loss in household income were compared, there were no significant differences among the scenarios, which made it difficult to select an optimum scenario.

For the Orange River System, the proposed alternative assurance of supply criteria indicated better results in terms of the timing and extent of curtailments than the assurance of supply criteria used in the Orange River Annual Operating Analysis. It is therefore recommended that further sensitivity analyses for the alternative scenario (User Priority B) be undertaken in future studies and investigated for implementation in the Orange River System.

In the Mhlathuze River System, the final scenario applying the *Modelling Support for Licensing Scenarios Study* seemed to be favourable in terms of results and specific economic indicators as well as for the extent and timing of curtailments.

A different approach was used for the Groot Letaba River System. Output files from WRYM – not WRPM – were incorporated in the new tool, which proved to work. This was a realistic approach to the economic analysis for the Groot Letaba River System, which is currently managed based on a dam-operating rule and not an allocation procedure. Additional scenario analyses for the Groot Letaba River System were not undertaken at the time since the main focus was on establishing a link between the WRYM and WIM. The model is in place to make necessary amendments and do sensitivity analyses in future. It is recommended that irrigation users be approached, and that suggestions for an improved and optimal operating rule be made and tested with the new decision support tool.

In addition to the ASM comprising outputs from the WRYM, WRPM and WIM, the crop production model is also used for enhanced interpretation of results and decision-making support. The crop production model is designed to determine if farmers will be able to continue farming on a sustainable level despite the curtailment of water supply for irrigation crops. The table that follows shows the viability results in the farm production model of a standard farm. On a 90% restriction level, the Great Fish River System (part of the Orange River System) was the least feasible among the study areas – considering all the elements of a production budget. In the Groot Letaba River System, a standard farm was also non-feasible, while a standard farm in the Mhlathuze River System was still feasible. However, this area would probably start to consider management options as it was getting close to a non-feasible threshold for continuous production.

Water supply curtailment		Orange–Fish River		Groot Letaba		Mhlathuze Scenario 1	
90%		Standard farm					
Change of nett farm income	i) % ii) R million	−106.4%	**−R 8.90**	−97.2%	**−R 18.01**	−92.5%	**−R 21.61**
Change on hectares	i) % ii) ha	−90.0%	**−270**	−90.0%	**−107.1**	−90.0%	**−108.0**
Nett income (profit/loss)	i) % ii) R million	−125.8%	**−R 1.82**	−102.8%	**−R 0.49**	−96.1%	**R 0.87**
Still feasible for producer	Yes/No		**No**		**No**		**Yes**

These findings are based on the nett farm income for one specific year. The crop production budgets are representative of each crop and catchment. For further research projects, it is proposed to conduct in-depth investigations for each production structure of the different crops.

It is therefore important that the ASM is used as support and in conjunction with existing methods used for decision-making pertaining to risk-based drought restriction analysis, which will be referred to and elaborated in this report.

This report is Deliverable 6 and the final report of the *Economic Study of Assurance of Supply Requirements for Water Resource Management with Reference to Irrigation Agriculture*.

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LIST OF ABBREVIATIONS

AOA	Annual Operating Analysis
ASM	Assurance of Supply Model
BWS	Bulk Water Supply
CMA	Catchment Management Agency
d/s	Downstream
DWS	Department of Water and Sanitation
EC	Eastern Cape
ELU	Existing Lawful Use
EWR	Environmental Water Requirement
FAO	Food and Agriculture Organization of the United Nations
FSC	Full Supply Capacity
GDP	Gross Domestic Product
HFY	Historical Firm Yield
HDI	Historically Disadvantaged Individual
HH	Households
HHI	Household Income
IFR	Instream Flow Requirements
IVRS	Integrated Vaal River System
IWRP	Integrated Water Resource Planning
LHWP	Lesotho Highlands Water Project
LO	Lower Orange
LOE	Lower Orange East
LOW	Lower Orange West
MW	Megawatt
MWAAS	Mhlathuze Water Availability Assessment Study
NFI	Nett Farm Income
NPV	Nett Present Value
NWA	National Water Act
NWRS	National Water Resource Strategy
ORASECOM	Orange Senqu River Commission
ORRS	Orange River Replanning Study
PES	Present Ecological State
R	Rand
RoR	Run-off River
RPF	Resource-poor Farmer
RSA	Republic of South Africa
RWS	Regional Water Scheme
SAM	Social Accounting Matrix
SFR	Stream Flow Reduction
Stats SA	Statistics South Africa
u/s	Upstream
UOW	Upper Orange West
WARMS	Water Authorisation and Administration Management System
WC/WDM	Water Conservation and Demand Management
WIM	Water Impact Model
WMA	Water Management Area
WRC	Water Resource Commission
WRPM	Water Resource Planning Model
WRYM	Water Resource Yield Model
WUA	Water User Association
WUL	Water Use Licence

1 INTRODUCTION

1.1 Background

Water is a fundamental source to life. The wellbeing of any country as well as its economic development are essentially interdependent on water as a resource. Although water is a renewable resource, it is also a finite resource, which is distributed unevenly both geographically and through time. In effect, this vital resource is increasingly recognised as an economic commodity, not overlooking its direct correlation to food security. Water is a limited natural resource and its natural distribution and availability make it challenging to meet the needs of all users all the time. The main factors influencing and threatening the availability of water are an increasing demand, occasional droughts and climate change. These factors emphasise the need for advanced water resource planning and proper management as a means to facilitate equitable water allocation among different regions and competing users.

As water is getting more scarce globally, water allocation plans and agreements have taken on increasing significance in resolving international, regional and local conflicts over access to water (Speed, 2013). While there has been some evolution in approaches over allocation, the fundamental process has remained the same. Once the water supply system is imbalanced, possible system intervention and augmentation options need to be considered. However, in a situation of drought, when water demands exceed the water supply capabilities of a supply system, a balanced system may incur a temporary water scarcity. The more viable option to maintain a system balance would be to implement water restrictions. Determining restrictions is an involved process and the implications thereof, especially on the economy, are far-reaching.

1.2 Objective

The objective of this research is to develop a decision support tool for assessing the assurance of water supply requirements of various water user sectors based on economic indicators by coupling existing water resource models with an economic model that is currently used in practice in South Africa. These models include:

- The water resource yield model (WRYM).
- The water resource planning model (WRPM).
- The economic water impact model (WIM).

Economic indicators include gross domestic product (GDP), employment, and household income. Sensitivity analyses must be done to determine the impact that reducing water supply has on the economic indicators within a water supply system. User priority (risk criterion) is the main variable as input to the WRPM for the analyses to be undertaken.

The water supply systems identified for testing this tool are:

- The Orange River System.
- The Groot Letaba River System.
- The Mhlathuze River System.

These systems have diverse water requirements – especially in terms of irrigation agriculture. The new assurance of supply model (ASM) serves as a decision support tool that can be used to improve assurance of water supply criteria, thus enabling economically optimal management of water resources and equitable water supply in times of drought.

1.3 Motivation

For the past 25 years, drought management has been analysed with various models. Distinction was made between different priorities and associated risk levels in terms of water supply to users in drought conditions. When water demands exceed supply capacity, consideration should be given to prioritising water consumers according to the economic return of the products produced with the available water within the system. The difficult task of the water resource manager is to decide whom to curtail and by how much, in such a manner that a total system failure does not occur. The process to decide at which level of assurance water should be supplied to the different user sectors has mostly been based on discussions among knowledgeable stakeholders representing each sector located within the water resources' areas of supply. The definition of the priority classification or criteria for risk of curtailments has largely been based on expert opinion and qualitative economic criteria. The driver behind stochastic risk and drought water-restriction analysis is the priority classification of the different water user sectors. This research is to apply quantitative economic analysis to improve on the status quo in terms of risk-based drought water-restriction analysis.

1.4 Scope

The methodology that will be applied to obtain the objective entails an iterative process and sensitivity analyses using existing in-practice computer models. The computer models to be used include:

- WRYM.
- WRPM.
- WIM.
- Farm production model (Microsoft Excel™ spreadsheet).
- Reservoir monitoring utility (Excel™ spreadsheet).
- Combined new model developed with Excel™ Visual Basic Script.[1]

The water resource catchments identified for the study area are located in South Africa and include:

- The Orange River System.
- The Groot Letaba River System.
- The Mhlathuze River System.

Data for these catchments is readily available and detailed studies of water supply have been conducted in each of these areas. Changes for inputs to the WRPM and WRYM for the analyses to be undertaken will explicitly be made to the priority classification of different user sectors as well as the storage operating levels of the dams within the water resource supply systems.

To determine the economic impact of a reduced water supply to different water user sectors, the loss in the following economic indicators will be determined:

- GDP value (in South African Rands).
- Employment (in numbers).
- Household income (in South African Rands).

Furthermore, present values for each of these economic indicators will be derived for the analysis period of 10 years. A longer analysis period of, for example, 25 years would be more ideal as it would include wet and dry periods; however, these analyses take up to 24 hours, which is considered too long for the time and budget of this research study. Also, the main focus is to develop a functional ASM and the

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[1] This model will be an update of the existing reservoir monitoring utility and is referred to as the assurance of supply model (ASM).

analyses to be undertaken are primarily for testing the model. These limitations can be addressed in future research studies.

Each water user sector needs detailed analyses to optimise the assurance of supply requirements. However, the economic model to be used, the WIM, was only developed for the irrigation agriculture sector. This does not imply that other sectors cannot be incorporated in future studies as other sectors such as mining, industries and services sub-sectors feature respectively in the primary, secondary and tertiary sectors in the total economy. The economic effect of the changes in the user priority and risk criteria on the other water user sectors thus have potential to be researched further to improve the link between the economic model and the ASM. The WIM considers backward linkages (direct, indirect and induced impacts) and not forward linkages. Detailed research regarding the forward linkages – in particular linking to the resource models – is also an objective to consider for future studies.

The application of the WIM includes changes to be made to crop prices for the chosen base year, which is 2016 for these case studies. The reduction in water supply based on the outcome of the analyses carried out by the WRPM will then enforce a price level change. By making these changes, the model automatically calculates the socio-economic effect of an amended crop yield due to a different percentage water supply than normal. A change in water supply as input to the WIM represents any years specified for the planning period in the WRPM, but is individually analysed and does not account for an economic carry-over effect of any reduction in water supply of the previous year. However, any changes made to the assurance of supply requirements of the irrigation agriculture sector will affect the assurance of supply to other user sectors as well. Therefore, existing methodologies used for analysing the user priority classification or criteria for risk of curtailments need to be consulted as well. These include storage projections of the water resources in the water supply system generated with the WRPM as well as the short-term yield reliability curves of the water supply system determined with the WRYM.

Although the WIM does not yet make provision for long-term planning and only has an input for the current and a new scenario as per economic region, it does have possibilities for forecasting. One of the drivers of the WIM is the crop production budget (enterprise budgets) per crop and, in the case of long-term crops, the budget makes provision for the costs and crop yield per year.

The initial planting costs are accommodated in Year 1 with a gradual increase in crop yields till the maximum tonnage is attained. The weighted average budget used in the WIM accommodates all the above variables over a time period. As there are many variables in a crop production budget, a weighted average budget per individual crop was used. It can be argued that it is a limitation to the modelling system; however, it keeps the emphasis on the effect of the water and hectare changes using an economic term *ceteris paribus* (with other conditions remaining the same; other things being equal) concept. This enables the user to pinpoint the effect of water management changes.

Broadly speaking, the financial impact on the individual producers and eventual economic impact in an area will depend on a number of factors, which include:

- The intensity of restrictions at Level 1, Level 2 or Level 3.
- The length of the restriction period.
- The crop mix used by the producer.
- The financial situation of the producer before introducing restrictions.
- The size of the farming operation.

These factors will differ between regions and producer groups. As this study does not include detailed fieldwork, the assumptions are general and the deductions have a generalised format consisting of representative data to be able to provide realistic results.

2 LITERATURE REVIEW

2.1 Assurance of Supply

Speed (2013) defines reliability or assurance of supply of a water entitlement as “a measure of the probability of a certain volume being available under the entitlement”, which “are typically expressed by reference to a statistical performance indicator and calculated water resource management models”. The two main elements of a water entitlement are its volume and reliability in terms of water availability. The assurance of supply is essentially the defining factor of a water entitlement, which influences its performance over the long term and under varying conditions. Entitlement holders need to know from the assurance of supply allocated to them how much water they can expect, how often they will be supplied with less than their full entitlement, the volume less than the norm, and the minimum volume they can expect to receive under extreme conditions. Furthermore, entitlement holders need to be aware of the variability of the availability of water during any given year.

The challenge remains in the decision of supplying different user sectors at different levels of assurance based on the availability of water and economic growth associated with the various water user sectors. In general, water allocation plans intend to allocate water based on historical use as well as the political power of constituencies involved regionally or per user sector. An approach of strategic development that considers more complex economic and social features may be required in a stressed water supply system when it comes to defining allocation plans. For example, if a strategic water user needs a high assurance of supply with the probability of system failure not more than once in 200 years, the assurance of supply equates to 99.5% with a probability of failure of 0.5%.

The South African National Water Act (NWA) dictates water be allocated directly to individual users and not regionally. In the Inkomati Catchment area, the challenge of the variability of water availability was addressed by only allocating water that could be supplied in most years. An assurance of supply normally higher than 85% formed the basis on which water allocations were granted. Although such an allocation plan contributes to security in investing in water-consuming enterprises, there is less water available for allocation. More water can be made available at a lower assurance of supply. Politically this can cause ructions, a situation that further motivates the importance of developing practical guidelines and criteria for the decision-making of assurance of supply allocations.

In Pakistan, for example, water from the Indus River is allocated by the Indus Water Accord among four provinces based on an average annual volume of water available in the system and two crop-growing seasons. If surplus water is available, smaller provinces are prone to get more water than their normal allocation. There are still disputes regarding the allocation of water for environmental requirements. The water from the Yellow River is allocated to 11 provinces based on the mean annual availability thereof. The proportional shares to the various provinces have been set in the 1987 Water Allocation Scheme to which the water allocated is increased or decreased accordingly.

A new basin allocation agreement was made for the Lerma–Chapala basin in Mexico in 2004. This agreement is defined by the outcomes of a hydrological model that takes cognisance of the various sub-basins and user sectors, and derives allocation entitlements accordingly based on a linkage between environmental conditions in the lake and anticipated water availability. This detailed agreement entails three allocation scenarios for the various irrigation districts in the upper reaches of the basin among others. Based on the range of run-off within each irrigation district, the maximum allowable abstraction volume is indicated. An additional criterion for maximum abstraction from the Lake Chapala basin is the storage volume of the lake on 1 November each year. The storage level of the lake dictates the definition of the three abstraction scenarios being either critical, medium or abundant, which ties in with three run-off classifications respectively to ultimately determine the maximum abstraction volume.

2.2 The Value of Water in a Social and Economic Sense

This evaluation of the value of water is often a difficult task since costs and benefits do not only occur once but form part of a continuous system (Mullins, 2014). Furthermore, costs and benefits are often hidden, which make them hard to identify, and they are also frequently difficult to measure. An important objective of economic policy is improving living standards, which implies the increased consumption of goods and services (Mullins, 2014). As a result of the scarcity of economic resources, current consumption competes with future consumption. Therefore, the policymaker should – implicitly or explicitly – weigh current consumption against consumption at every stage in the future. Where the government emphasises current consumption, the situation will probably be characterised by relatively low tax rates and low levels of saving and investment. Should the premium be placed on deferred consumption, the opposite will most likely occur. Naturally, it is politically difficult to persuade the public to defer consumption because it is normally associated with unpopular policy measures such as higher taxation.

A further important objective of economic policy is that of equity (Mullins, 2014). In this case, it is necessary for the planner to allocate weights to the value that consumption has for different individuals, which are normally grouped into certain income groups and/or regions. It is accepted that as a family group moves up the income group ladder, water use will increase – especially in South African urban areas. But with the densification of middle income group suburbs, the size of erven decreases and water use for gardens also decrease. The appropriate weights can be derived from the principles underlying the policy; they do not necessarily have to be quantified. For example, progressive taxation systems reflect the greater weight that the planner assigns to lower-income groups relative to higher-income groups.

Since resources are limited, an important consideration is to find optimal combinations of resources through which the nett community benefit can be maximised. The values of inputs and outputs depend to a large degree on the level of development of the economy in which prices are determined. Market prices of products and services often do not reflect the real value (scarcity value) of products and services since governments interfere in the operation of product and services markets through, for example, tariff protection, taxes or subsidies. To assess the economic effectiveness of the application of resources within projects, it is essential that the prices of inputs and outputs indicate their economic scarcity value. Scarce resources are traded at specific prices, namely, market prices. Provided certain conditions are met, prices are the best criteria upon which the allocation of resources for specific uses can be based. The assumption is that markets are perfectly competitive and that supply and demand determine the prices of inputs and outputs. When the free operation of markets is interfered with by, for example, restricting or stimulating either supply or demand or by price interference, market prices do not reflect economic scarcity values and the use of shadow prices becomes necessary.

2.3 Applicable Studies

2.3.1 The management of water resources through simulation

In 1998, Armer completed his dissertation on the management of water resources through simulation where he used the Marico–Bosveld Government Water Scheme as case study. The focus of his study dealt with the degree to which the risk of water supply in agricultural economic modelling is addressed. Armer (1988) mentions the lack of efficient techniques for risk programming in terms of water supply and irrigation schemes. To him it seemed as if the integral knowledge and insight in the different social sectors – especially in terms of agricultural economy and water supply – are completely under-emphasised in the Republic of South Africa (RSA). The level of risk against which the Department of Water and Sanitation (DWS) is willing to provide water to irrigators, is still precarious for economically viable farming.

Also, the management of water resources is not necessarily economically optimal. Hydrological and agricultural economic modelling has always been processed independently of one another. It is important that the risk associated with the supply of water be carried through to the economic analyses in RSA. One of Armer's (1988) objectives was to philosophise about using stochastic modelling to determine the norms against which water shortages can be considered as disaster droughts.

Stochastic analyses were done using 201 stochastically generated flow sequences – each with a record length of 40 years. The initial Marico–Bosveld Dam storage was kept at 100% for all analyses. The two scenarios tested consisted of the existing operating rule, which aimed to supply the full nett demand of 13.85 million m³ per annum, and a two-year short-term stochastic operating rule at a 1:10 year recurrence interval.

Two models were identified in the agricultural economic modelling. Model 1 included tobacco and chillies cultivated in the summer, and wheat in the winter on 26 ha respectively. Model 2 included chillies and wheat cultivated on 29 ha respectively. For the economic analyses, the agricultural income and expenses patterns for these farming divisions were considered. Table 1 summarises the fixed farming expenses.

Table 1: Fixed farming expenses: Marico–Bosveld Government Water Scheme

Item	Model 1 (Rands)	Model 2 (Rands)
Overhead costs	14 100	7 682
Instalments on loans	9 687	7 000
Water tax	4 992	5 568
Domestic expenses	27 600	20 625

The overhead costs include insurance, licences and diverse farming expenses such as auditor fees, membership fees and telephone costs. The divisional budgets accounted for fixed expenses such as labour and electricity. The instalments on loans made provision for a real interest rate of 8%. Table 2 summarises the economy of the specified farming divisions and represents the input/output relationships in terms of the working capital at an average management level and specific returns. The direct allocable costs include fertiliser, fuel, weed and pest control, labour, electricity, maintenance of vehicles, implements and irrigation systems.

Table 2: Economy of farming divisions

Crop	Yield (ton/ha)	Gross income (R/ha)	Direct allocable costs (R/ha)	Gross margin (R/ha)
Tobacco	2.2	20 148	12 895	7 253
Chillies	2.2	8 470	4 457	4 013
Wheat	3.5	2 566	1 758	808

Gross irrigation requirements, which include effective rainfall, are also a very important component of the data acquisition and the water requirements in m³/ha for the specified crops (Table 3). Wheat typically requires 6000 m³ of water for a yield of 5.5 ton and higher.

Table 3: Crop water requirements (m³/ha)

Months	Tobacco (early)	Tobacco (late)	Chillies	Wheat
January	1 600	1 320	1 330	
February	370	1 700	1 630	
March		1 250		
April		260		
May				
June				218

Months	Tobacco (early)	Tobacco (late)	Chillies	Wheat
July				502
August				1 164
September			410	1 476
October	480		710	640
November	1 300		1000	
December	2 350	480	1 330	
Total	**6 100**	**5 010**	**6 410**	**4 000**

Dynamic linear programming was used to test the economic financial feasibility of farming over time. The model consisted of matrices representing every production year. The matrices were linked by capital transfers and land use patterns. The model used a planning period of 20 years to maximise the nett cash flow. The water quotas of the first 20 years of the 201 predicted stochastic flow sequences for the two identified operating rules were read into the dynamic linear programming model using a linking program. After completing 201 iterations, the nett annual cash flow for each sequence was automatically placed in an output file from where the probability of the nett cash flow of a specific extent realising for each year could be determined. The results indicating the nett cash flow against the full water quota are summarised in Table 4.

Table 4: Nett cash flow per annum

Year	Nett cash flow (R)		Year	Nett cash flow (R)	
	Model 1	Model 2		Model 1	Model 2
1	47 190	46 337	**11**	64 489	33 893
2	49 656	27 628	**12**	66 760	34 481
3	41 402	20 628	**13**	68 096	35 012
4	54 206	20 599	**14**	69 458	35 712
5	56 160	20 687	**15**	75 005	37 110
6	57 283	21 100	**16**	76 505	37 852
7	58 428	21 522	**17**	78 035	38 609
8	63 141	25 495	**18**	73 577	33 363
9	64 403	26 005	**19**	75 049	34 030
10	64 187	33 140	**20**	76 550	34 710

The climbing trend in cash flow over time is a direct result of the reinvesting of surplus cash of the savings activity to the nett cash flow. The same trend can be observed if structural change in the farming pattern was to be made. The probability of maximum possible income level being reached decreases over time. However, results show that supply of the full quota over a planning period of 20 years for both operating rules is possible. From the box plots generated as output to the model and representing the probability distribution, it seemed as if the short-term stochastic operating rule contributed to an increased probability of certain cash flow amounts being reached over time. This can be attributed to the higher supply in terms of the water allocation. Another factor that can result in bigger fluctuations in the nett cash flow during dry periods is the cyclicality of rainfall.

When ultimately looking at the risk requirements for different user groups, irrigation is normally categorised at the highest risk of a 1:10 year recurrence interval or lower. Armer (1988) questions the possibility of using a resource in such a way that water is supplied to various agricultural users in compliance with their individual water requirements in terms of the risk of water allocation. Compensation releases might be too low for the distribution losses and users will have to first reflect on the demands at different risk levels. In addition, Armer (1988) stresses the need for further research in agriculture-economic modelling. Risk assessment and decision-making can intercept the propensity of agricultural water users to make larger plantings as allowed by the available water resources.

Figure 1 illustrates Armer's (1988) proposed agriculture-economic modelling.

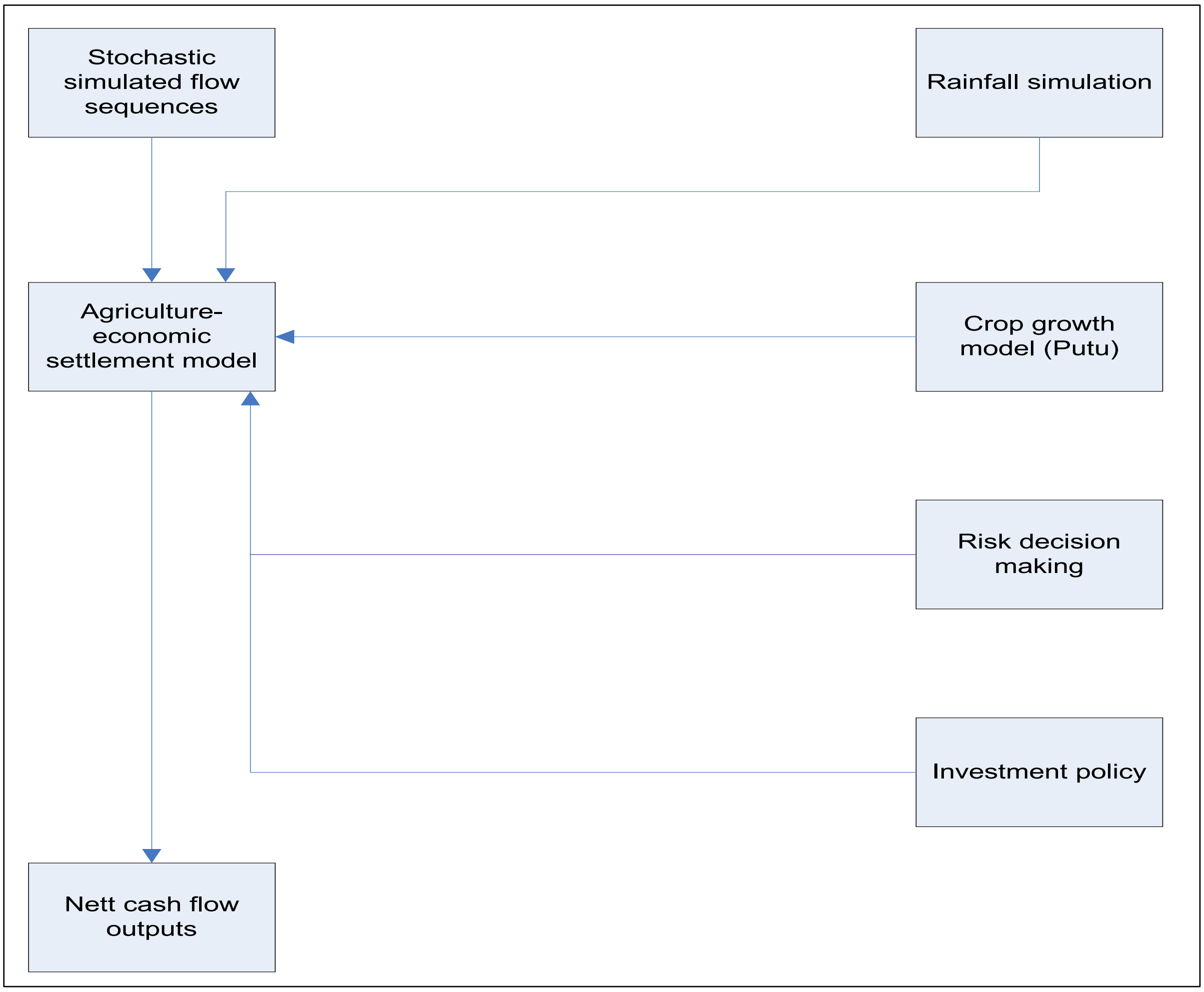

Figure 1: Armer's (1988) proposed agriculture-economic modelling

2.3.2 Annual operating analysis

An annual operating analysis (AOA) is important for the short-term planning and operation of a water supply system, and is undertaken in some of the bigger catchments in South Africa. The AOA is mainly driven by the starting storages of the system's impoundments at the beginning of a dry season and the short-term demand projections of all major water users in the system. This exercise entails a balance check between the available water in the system and the demand. A user priority classification is discussed and agreed with all stakeholders: the various water user sectors are each allocated an assurance of supply at which they will receive their water. These various classes of assurance are then incorporated into the WRPM to determine the exact time and volume for water restrictions to be implemented within the system. The short-term stochastic results from the model mimic the probable behaviour of the system, which is monitored accordingly. This enables operators to plan ahead – especially in times of leering droughts.

The priority classification adopted for the 2016/2017 planning year of the Orange River System's AOA (Table 5) was similar to that used in the Orange Integrated Water Resource Management Plan. The results from the WRPM analysis in May 2016 indicated that 10% restrictions were required for water users from the Orange River System. One of the repercussions resulting from the drought in 2015 was that all water supply for irrigation to the Kalkfontein Water User Association (WUA) was terminated and irrigators had no allocation for irrigation for the 2016/2017 water year.

Table 5: Orange River System priority classification 2016

User sector	Priority categories: portion of water requirements (%)		
	High	Medium	Low
	1:200 year (99.5%)	1:100 year (99%)	1:20 year (95%)
Irrigation	10	40	50
Urban	50	30	20
Operational requirements	100	0	0
Environmental	68	0	32

2.3.3 Thukela–Vaal transfer scheme

In November 2015, an unpublished scenario risk analysis (and effectively a rapid cost/benefit analysis) was done for the Thukela–Vaal Transfer Scheme, which compared the likely savings in pumping costs with the expected loss in economic production due to drought restrictions for selected scenarios. The need for this analysis was identified at the annual Stakeholder Operating Forum meeting in June 2015 where it was established that full pumping would be necessary from the Thukela–Vaal Transfer Scheme from November 2015 until further notice. This decision was made to decrease the risk of drought restrictions in the Vaal River System in the following five to 10 years. An interbasin transfer has a priority of strategic importance, which in this case, is mainly based on supplying water to the strategic industries located in the Gauteng region. These industries have a significant contribution to the GDP and 100% of their supply was allocated to the high-priority class, which assured them a water supply of 99.5%. Table 6 indicates the priority classification for the Vaal River System as applied in 2015.

Table 6: Vaal River System priority classification 2015

User		User priority classification (assurance of supply)		
		Low 95%	Medium 99%	High 99.5%
		Proportion of water demand supplied (%)		
1	Domestic	30	20	50
2	Industrial	10	30	60
3	Strategic industries	0	0	100
4	Irrigation	50	30	20
Restriction levels: 0 1 2 3				

The two main scenarios compared included:

- The Reference Scenario – where 20 m³/s needed to be pumped from October 2015.
- The Eskom Scenario – where 6 m³/s would be pumped initially, which only increased to 20 m³/s by June 2019.

The Eskom scenario resulted in higher drought restrictions and the required implementation thereof a year earlier than required for the reference scenario. Entering low-level restrictions means that domestic, industrial and irrigation users need to be partly restricted, which has possible far-reaching economic implications. Required cost/benefit analyses as well as sensitivity analyses must be done to better motivate the final scenario to be selected for implementation.

The simulated drought restriction results for the various scenarios were multiplied with the GDP production water-use relationship to determine its influence on the pumping cost and economic production. The pumping cost is simply the unit cost for transfer multiplied by each scenario's simulated water transfer volume. A present value was determined based on the differences in the various pumping scenarios for each year of the planning period. The economic production and differences between the present values of the transfer costs were compared to indicate the likely monitory gains or losses. The economic production dependent on water supplied from the Vaal River System was obtained from the *Classification of Significant Water Resources (River, Wetlands, Groundwater and Lakes) in the Upper, Middle and Lower Vaal water management area (WMA) 8, 9, 10: Status Quo Report* (DWA, 2011). The escalated prices for 2015 are given in Table 7.

Table 7: Economic production – Vaal River System

Sectors	GDP (R million)		Income households (R million)	
	Direct	Total	Low	Total
Irrigation agriculture	1 832	6 072	9 927	5 837
Mining	50 247	101 134	2 651	41 287
Manufacturing	105 374	240 777	10 029	159 911
Power generation	44 289	57 011	1 668	23 942
Total	**201 742**	**404 993**	**24 274**	**230 978**
		Total production: 635 971		

In 2014, South Africa's GDP was R3008 billion (Stats SA, 2014), which indicates that the GDP of R636 billion for the Vaal River System, contributing only 21% to the country's GDP, was a conservative estimate. Nonetheless, estimates of the GDP production associated with the different levels of drought restrictions per user sector in the Vaal River System were derived based on Table 6 and Table 7.

The results indicated that for Level 1 restrictions, R15 billion worth of economic production would be lost. For Level 2 restrictions, there would be a reduction in economic production of R134 billion. For Level 3 restrictions, the volume water restricted equates to R635 billion loss in economic production. The findings from this analysis indicate the effect of the priority classification and essentially the assurance of supply of water to different user sectors on the economic production within that sector, regionally and eventually the total GDP of the country.

3 METHODOLOGY

3.1 Overview of the Methodology

Assuring water supply affects the economic viability of a farming unit. Therefore, in researching the required assured supply of water to a particular user category, it would be necessary to determine the economic viability and financial resilience of irrigation farming. A financially viable farming unit has been defined in the past as one that at least covers farming expenditure and domestic expenditure in the long term and can generate its own capital for continued activities. For a particular farming unit, a link is required to the relevant water resource to determine to what extent (severity, duration and repetition) the unit can absorb a curtailment of water supply and what the effect on crops will be.

The water supply to the selected irrigation regions will be analysed using the WRPM that has been configured for each of the water resource systems and currently used in various DWS studies. Stochastic and systems analysis techniques will be used to analyse the water supply and curtailments for a various selected assurance of supply criteria for the three selected irrigation regions and to then establish the water supply/curtailments for each scenario.

The estimation of the impact of any water allocation changes will be implemented based on the WRPM scenarios available. To accomplish this, an econometric model approach based on the input-output model will have to be constructed for each of the economic regions. The WIM will be used to express the socio-economic impacts. The WIM is in the form of a dynamic computerised water entitlement model that can be used to identify and quantify economic benefits, maximum possible water reduction and capitalised impact. The WIM will be used to estimate the economic consequences of the WRPM scenarios to determine the relative impact of the water availability change.

Firstly, the WIM will be used to determine the current situation, which will be extended with the use of a multiplier methodology. Although the end result of the multiplier consists only of a numerator/ denominator, which is embedded in the WIM, the backbone of the direct, indirect and induced multipliers is the social accounting matrix (SAM) and the Leontief inverse matrix, developed by Nobel prize winner, Wassily Leontief, in economic sciences in 1973 (Wikipedia). The multiplier can be used when calculating the impact of any water supply changes. For the purpose of this study, it will be expressed in economic indicator ratios, namely, GDP/water, labour/water and in the income to be distributing to the household income/water. Furthermore, ratios will be determined on each specific economic region identified. It will, as was determined for the current situation impacts, also be expressed in terms of the indicators, namely, GDP, employment, and the distribution of income to the total households. It will identify changes if water is reduced at a specific catchment in the irrigation sector.

This amended crop yield resulting from a reduction in water supply takes the total life cycle of the crop into account whether it is a short-, medium- or long-term crop. The outcomes are the economic indicators including GDP, household income and labour per economic region. The relationship between crop yield and water supply, which is currently configured in the WIM, subsequently takes on a linear approach.

By linking the WRPM and the WIM, a relationship can be derived that indicates the effect of a reduction in water supply on the various economic indicators signifying the cause and effect of water supply changes expressed in economic terms. Crop detail and varying assurance of supply requirements are incorporated into the WRPM to determine the available supply for a given restriction rule scenario.

The user priority and risk criteria definition, or table in the WRPM, is the primary input data set that will be varied in the scenario analyses. The economic implications of alternative assurance of supply criteria for the user priority table will be evaluated with the aim of finding the optimum or most suitable set of parameters. Up to a 1000 sequences are simulated in the WRPM for a single year, which results in a

1000 different possibilities to reduce water supply. Provision will have to be made in the WIM to automate the process of incorporating the results from the WRPM instead of by manual input.

The present value of the economic indicators will be used to have one single comparable value for the economic output of the WIM for all the simulated sequences for each scenario per selected study area. To account for the time value of a time series of monetary metrics, the present value of each of the 1000 sequences will be calculated to provide a probability distribution of the present value for each scenario.

The following sub-sections explain how the different water resource models used by water engineers and econometric/economic models applied by resource economists link to create this unique modelling system developed.

3.2 Water Resource Models

3.2.1 Resource capability

All water resources have a finite supply capability with respect to available volume. In order to establish the water supply capability of a water resource system, it is important to initially conduct a hydrological analysis. Such an analysis typically considers the characteristics of the water resource system. These characteristics include natural aspects such as rainfall, evaporation, streamflow, alien invasive plants and wetlands. Further characteristics include human activities such as agricultural and urban development, mining, stream flow reductions (SFRs), water transfer schemes, streamflow diversions and other interaction with water bodies in the catchment.

Based on the historical data of these aspects and a selected development level of water requirements abstracted from the water resources, it is possible to determine the historical firm yield (HFY) of a water resource system. The HFY refers to the maximum amount of water that can be abstracted from a water resource system without causing the system to fail. A water resources system failure occurs when the water in the system is depleted to the point where no further abstraction can be made or no more water can be supplied from the system to the users. Figure 2 indicates the HFY with a red dot on a yield versus target draft graph. Even though the system might have the potential to yield more beyond the point of “firm” yield, it is not ideal since the system will experience an increasing number of failures at an increased target draft beyond the point of HFY.

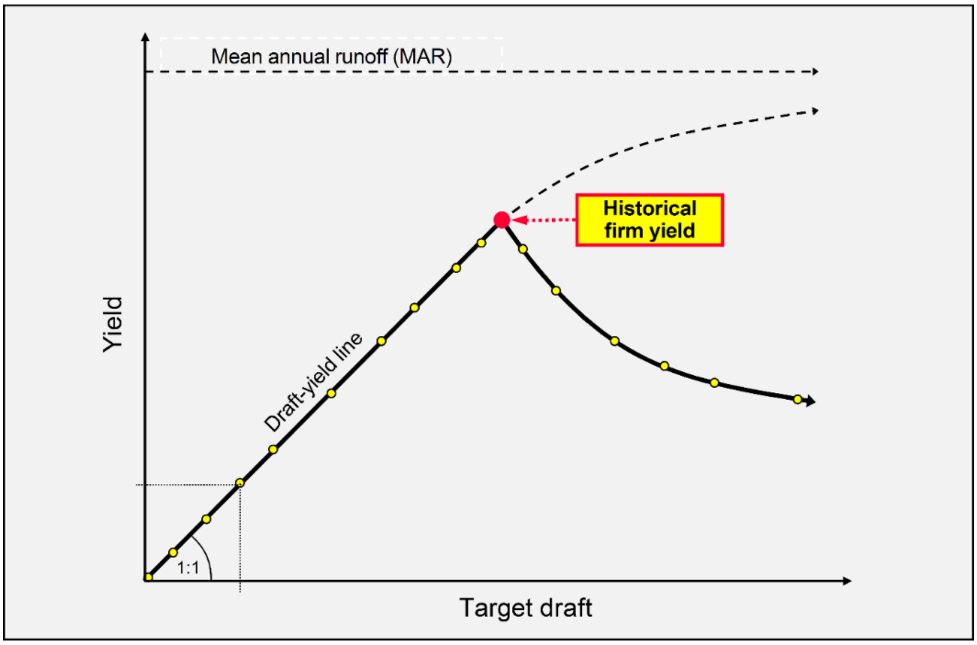

Figure 2: Example of a target draft versus yield diagram (DWAF, 2008)

Normally, an HFY analysis is only based on a single historical streamflow sequence, which mainly depends on the severity of dry periods in a given record period. Due to the limited length of the historical record and the knowledge that the previous sequence of events (wet and dry periods) will not be replicated in future, the reliability of supply associated with a specific HFY can only be determined by doing additional stochastic yield analyses.

Stochastic analyses are typically undertaken to either determine the water resource system yield over a long- or short-term period at a specific development level; it is especially applicable for water resource planning purposes and allocation decisions. With stochastic analysis, the water requirements on the system at the point where the HFY of the system was determined are also considered, as well as the initial capacity (capability) of the resources in the system at the start of the planning period. The primary result of stochastic analysis is the yield-reliability curves that are derived from stochastically (synthetically) generated monthly hydrological streamflow time series sequences. The characteristics of these curves in turn represent the assurance of supply (or risk of non-supply) associated with a range of abstractions (yields) at different recurrence intervals of a drought period.

In Figure 3, the colour lines are the different target drafts or yields, which after the break point (indicated by the black dots) become the base yield lines. The base yield lines represent the yield data points of the system for each individual analysed sequence fitted as a third-order polynomial equation. The black line connecting all the break points of the analysed target drafts is known as the firm yield line. The x-axis represents the probability of the target draft exceeding the availability (yield) of the system, which is expressed as a percentage of the number of the total sequences failing to meet the target at a given recurrence interval expressed in years (risk of a single supply failure in x number of years). In addition to the short-term stochastic yield analysis, which is normally conducted for an analysis period of five years or less, a long-term (50 to 80 years) stochastic yield analysis can also be carried out for planning purposes and to evaluate the need for water supply interventions.

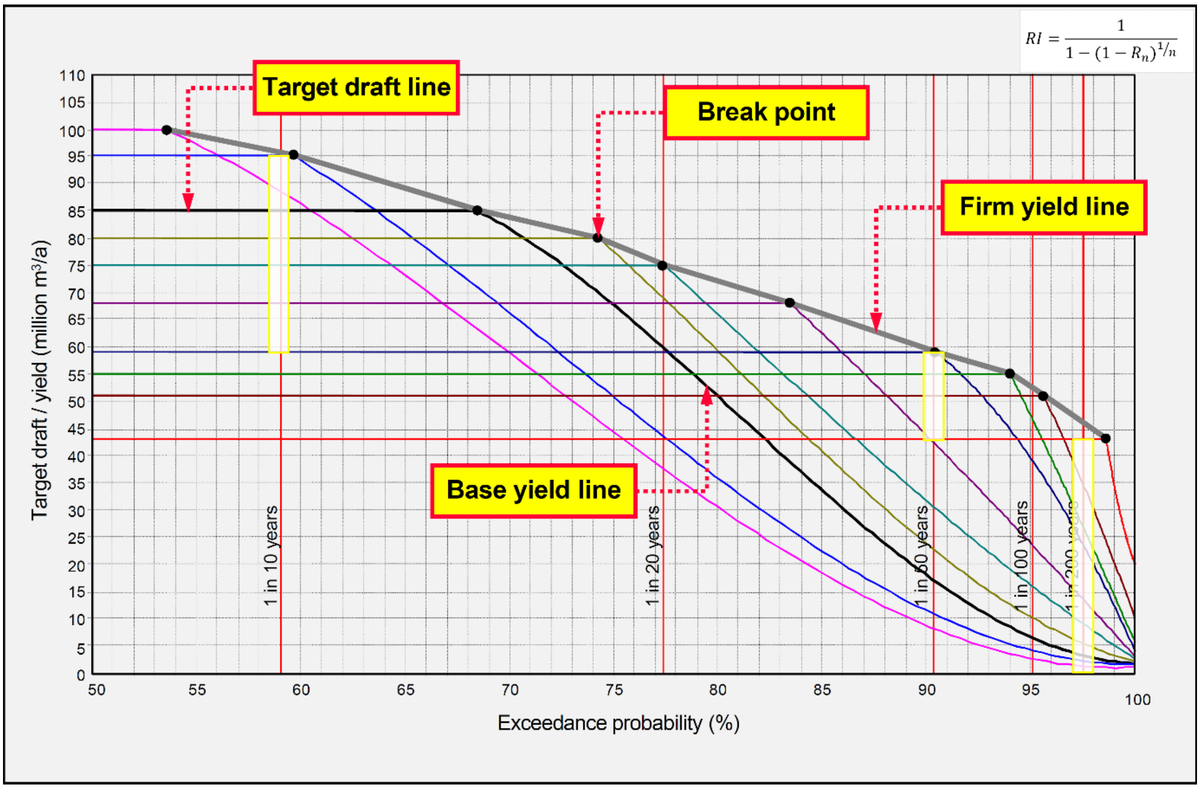

Figure 3: Example of a set of yield reliability characteristics curves (DWAF, 2008)

3.2.2 Assurance of supply and user priority

An already stressed water resource system is likely to become increasingly stressed over time – especially if the system has a finite supply capacity and a growing demand. Therefore, it is important to consider the reliability or assurance at which the demand on a water resource system can be satisfied under various conditions without system failure. As explained earlier, a stochastic analysis can be undertaken to determine the assurance of supply, which is illustrated by yield reliability curves. The assurance of supply is expressed as a percentage resulting from the probability of a water resource system failing to supply the demand or target draft thereon at different recurrence intervals of drought periods. For instance, if a system were to fail to supply a demand only once in 200 years, it has a risk of failure of 0.5% and an assurance of supply of 99.5%.

Table 8 lists the most common risk of failures used for stochastic analyses at the corresponding assurance of supply.

Table 8: Recurrence interval – Risk of failure – Assurance of supply

Recurrence interval	Risk of failure (%)	Assurance of supply (%)
1:200 years	0.5	99.5
1:100 years	1	99
1:50 years	2	98
1:20 years	5	95
1:10 years	10	90

The total demand on the water resource system is allocated at different levels of assurance of supply in order not to exceed the firm yield of the system. If a total demand of 95 million m^3/annum is drawn from the water resource system (illustrated in Table 9), 43.5 million m^3/annum can be allocated at a risk of failure of 1 in 200 years, 15.5 million m^3/annum at a risk of failure of 1 in 50 years, and 36 million m^3/annum at a risk of failure of 1 in 10 years. However, if the total demand increases over time to 110 million m^3/annum or the storage in the resource decreases, the water resource system will experience a deficit in demand versus supply and will be imbalanced. This may require a reassessment of the allocation of the total demand at different assurance of supply levels, curtailment of the supply or system interventions. Less water can be supplied by the system if the assurance of supply requirement is high and the starting storage of the system is low. The combination of these two factors can have a disastrous effect on the water resource system and economy. Therefore, it is important to consider different starting storages of the various resources within the system when doing yield analyses in order to mimic an envelope of possible situations in reality.

Figure 4 illustrates the short-term yield reliability curves for starting storages of the water resources in the system from 20% to 100%. The green bars indicate the volume the system can yield in million cubic metres per annum with the various starting storages at assurances of supply of 1 in 10 years and 1 in 200 years respectively. At a system starting storage capacity of 100%, 59% of the sequences analysed indicated that the system is able to supply a demand of 16.7 million m^3/annum at an assurance of 90%. For 97.5% of the sequences analysed, the system is able to supply 8 million m^3/annum at an assurance of 99.5%. When a water resources system is challenged with a potential deficit in available supply versus demand be it infrastructure related, due to a growing population, a drought or combination of all three, it is important to have by-laws in place to protect the water resources from complete failure. The allocation of water to various users from a water resource system is a challenging exercise – especially in semi-arid regions. However, in a constantly evolving and diverse socio-economic environment, different water users are demanding from a system where there are numerous interdependent variables to consider an optimal water allocation structure.

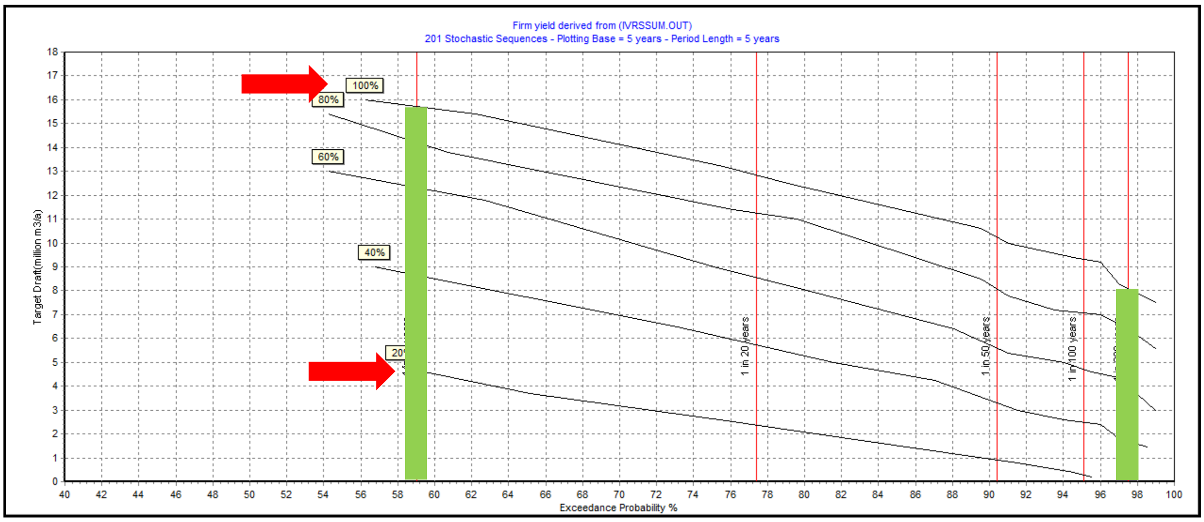

Figure 4: Short-term yield reliability – family of firm yield lines

The level of assurance of supply from the water resource system has played an influential role in a qualitative approach to water-use allocation. Different water users have different priorities in terms of the reliability of water supply as well as the risk of non-supply. Higher priority users request water supply at a higher assurance, which means they will settle for a lower volume as long as they are assured of that volume. Lower priority users normally require larger volumes of water and are willing to have it supplied at a lower assurance. Water users with a higher priority typically include users from the domestic sector providing water for basic human need and users from the industrial sector – especially those responsible for power generation and petroleum refineries.

The environment is considered as a high-priority user; unavoidable losses to the water resource system can be categorised as an imaginary high-priority user. In addition to striving towards an optimal water allocation in terms of water supply from the water resource system, it is vitally important to consider the possible need for water restrictions and the direct and indirect impact thereof on the different user sectors. To aid in the determination of restriction levels, the system and user categories can be tabulated against different levels of assurance of supply known as a user priority classification table.

Table 9 illustrates the process of priority classification for irrigation and domestic users at a variety of restriction levels based on the assurance of supply.

Table 9: User priority classification in percentage

System and user category	Priority classification (%)		
	Low (95% assurance) (1:20 year)	Medium (99% assurance) (1:100 year)	High (99.5% assurance) (1:200 year)
Irrigation	50	30	20
Domestic	30	20	50
Level of restriction	1	2	3

Once again, this specific allocation is derived from a qualitative approach by a group of decision makers and not based on a scientifically quantifiable approach. In this example there are three levels of assurance at which the system will supply; these are classified as low, medium and high priority.

In Volume 2 of this report, a detailed example is given for the application of the user priority classification table when a certain volume of water supply is curtailed. This method for determining the required level of restrictions will form the basis of the concept to be discussed in Section 3.5. Various water user priority classification scenarios will be defined on which further analyses can be conducted in order to find an optimised solution.

3.2.3 Risk of non-supply

After the short-term yield reliability characteristics of the water resource system have been determined, they are incorporated into the planning analyses to assist with water allocation management. The aim with planning analyses is to quantify the capability of a dynamic water resource system analytically, determine operating rules and schedule the implementation of development options using network simulation procedures and practical allocation strategy. This involves determining the ability of a water resource system to satisfy water requirements, which are distributed geographically and change with time.

The purpose of a curtailment strategy is to restrict water use during periods of drought in order to protect the resources of high-priority users (DWS, 2008). When revising the priority classification for different water users, the risk of non-supply is defined accordingly (see Section 3.2.2). High-priority users will typically demand water at an assured supply where the water resource system only fails to supply the demand once in 200 years, which is a high-assurance and a low-risk scenario. Planning analysis results are normally presented in the form of box-and-whisker plots. These plots provide a convenient way of depicting a probability distribution, especially if there are a number of probability distributions to be displayed on a particular graph (DWS, 2008). Box plots illustrating the results of planning analyses can include projected annual water demand versus system supply, projected annual water resource and system storage volumes, and projected annual system water curtailments. Figure 5 illustrates such a box-and-whisker plot, which indicates probability distribution as a probability of exceeding a given value.

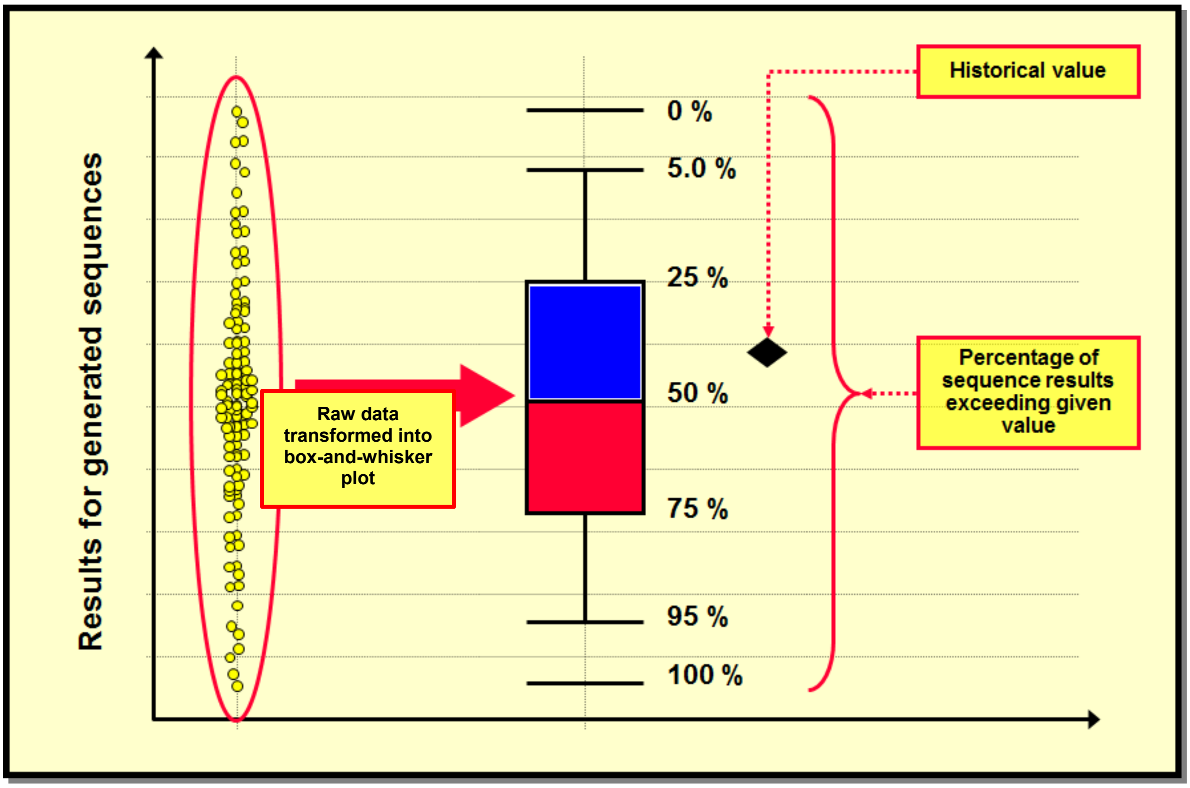

Figure 5: Box-and-whisker plot

One of the most important uses of stochastically generated streamflow sequences is to determine through projections if there are possible water supply problems moving into the future based on risk analyses. The stochastic streamflow sequences represent plausible future scenarios; some of which may be positive regarding water supply while others may be pessimistic. By generating and analysing a number of sequences (usually 101 or 1000), it is possible to develop a five- or 10-year projection indicating the likelihood (probability) of failure. Technically, it is possible to create projections 50 or 100 years into the future, but in practice, a five- to 20-year window is more than sufficient in most cases.

Normally, the analysis window is reanalysed each year so that a moving window is created. In this manner, the water supplier can assess whether or not the situation is deteriorating or improving. If the situation is deteriorating, the aim is to identify the risks and take remedial action early on in a drought period rather than allowing for severe restrictions to be implemented. In many droughts, it is possible to avoid the most severe restrictions if low-level restrictions are introduced at an early stage.

Figure 6 plots the risk of non-supply resulting from a multi-sequence stochastic analysis over a 20-year period against the risk criteria of a specific water resource system. In 2021, the 1% probability line of the box plot enters the second level of curtailments. This means that there is a 1% probability that the system will have a risk of failing to supply the demand once in every 100 years. It is a violation of the risk criteria requiring Level 2 curtailments.

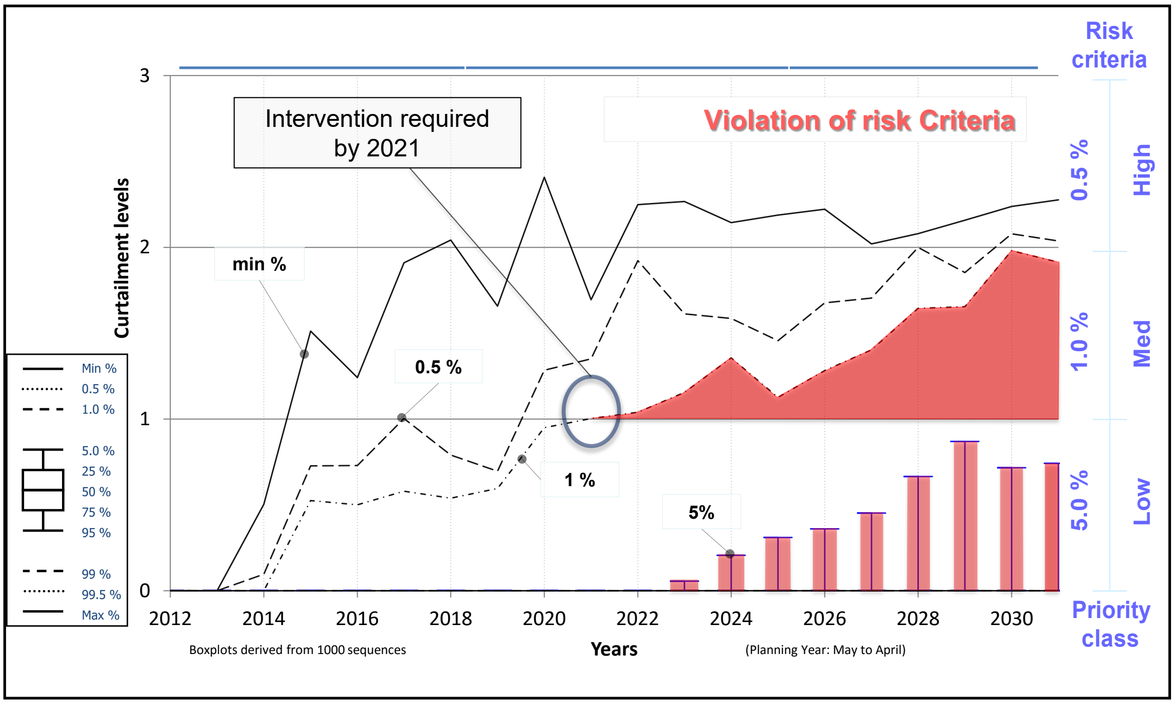

Figure 6: System curtailment plot

However, since this is planning analysis and this possible violation of the risk criteria in the future can be depicted at an early stage, intervention options should be considered to prevent the need for restrictions to counteract the risk of non-supply. In the first curtailment level, there is a 5% probability that the system will experience a risk of non-supply of 5% by the year 2023. Therefore, the risk criteria for the system are being violated and Level 1 curtailments will have to be implemented.

Various intervention options are planned to come into action at different time steps in the future. These include water conservation and demand management (WC/WDM) in the high water requirement projection, desalination for urban use, and the removal of unlawful water use. By analysing the effects of the risk of non-supply to the different water user sectors, more informed decisions can be made in terms of the prioritisation of water allocation to these different sectors and inherently how much each sector should be curtailed, if at all necessary.

3.2.4 Operating rules

"System operating rules are defined to address aspects like the supply priority among water users, prioritisation of the use of water sources, inter-reservoir and inter-sub-system support rules, as well as reservoir operational levels and drawdown rules. The selection of the operating rule is of great importance because they have a very direct impact on the capability, assurance of supply and sustainability of a system's water resources, as well as the costs associated with its operation. The standard procedure for developing operating rules involves a number of steps, which represents an iterative process that can be repeated as many times as required." (DWS, 2008).

The steps include selecting an initial set of operating rules based on chosen objectives regarding the behaviour of the system. These rules are implemented and analysed in a network simulation model of the water supply system.

"Thereafter the level of achievement of the selected objectives based on the behaviour of the system as exhibited in the simulation results is evaluated." (DWS, 2008).

When undertaking operational planning for a water resource system, an optimal operating rule is determined analytically through simulation and scenario analyses. The process consists of the following:

- Inter-reservoir operating rule optimisation within sub-systems.
- Evaluation of inter-subsystem transfer operating rules.
- Water quality blending operating rules.
- AOAs to determine short-term operating rules taking reservoir levels at a given point in time into consideration.
- Combined operation of water resource systems with hydropower and water supply as competing users.
- Assessments are usually based on scenario analyses where the objectives are to (DWS, 2008):
    - Maximise yield or extend the requirements for further intervention as far into future as possible.
    - Reduce operating costs (pumping energy) during periods of full system storage levels by deviating from the long-term operating rule.
    - Optimise the system operation with respect to water quality criteria. A balance between water quality and supply reliability has to be achieved.
    - Maximising hydropower generation without jeopardising the reliability of water supply or vice versa.

All water resource systems have infrastructure that require maintenance at some point. This may interfere with the normal operation of the system; therefore, it is important to have a system maintenance schedule in place to consider when developing an optimal operating rule.

Results generated with the water resource models provide the variation in water supply scenarios to be used as an input to the WIM discussed in Section 3.3.

3.3 Water Impact Model

The WIM provides a tool to create an appropriate economic baseline against which to measure the possible impact of changes in water availability by means of scenarios. When water scenarios/volumes are determined by the applicable water resource model, an economic analysis can be done for a river catchment, which includes large water users such as irrigation agriculture, and if necessary, commercial forestry, saw mills and food processing, which use water indirectly if it is included in the objective. Although the ecotourism industry is not a large water user and an indirect water user, the benefit lies in the attraction value of what the river and the water provide to the sustainability of the industry; therefore, it can be included into the analysis.

The specific water catchment is divided in regions of economic activities considering climatic and topographic issues, which are therefore evaluated as economic regions. The economic baseline of each economic region provides the impact of water usage if the full allocation is available based on variables such as GDP, employment, and income received by different income households. The economic value of water use for each category can then be determined.

To accomplish this, an econometric model has been constructed with the multipliers synthesised from a specific provincial SAM as basis. It is therefore referred to as a WIM. The WIM is a dynamic computerised water entitlement model customised for the irrigation sector whereby economic benefits, possible water reduction and capitalised impact can be classified and computed. The macroeconomic indicators are calculated by using the WIM, which is illustrated schematically in Figure 7.

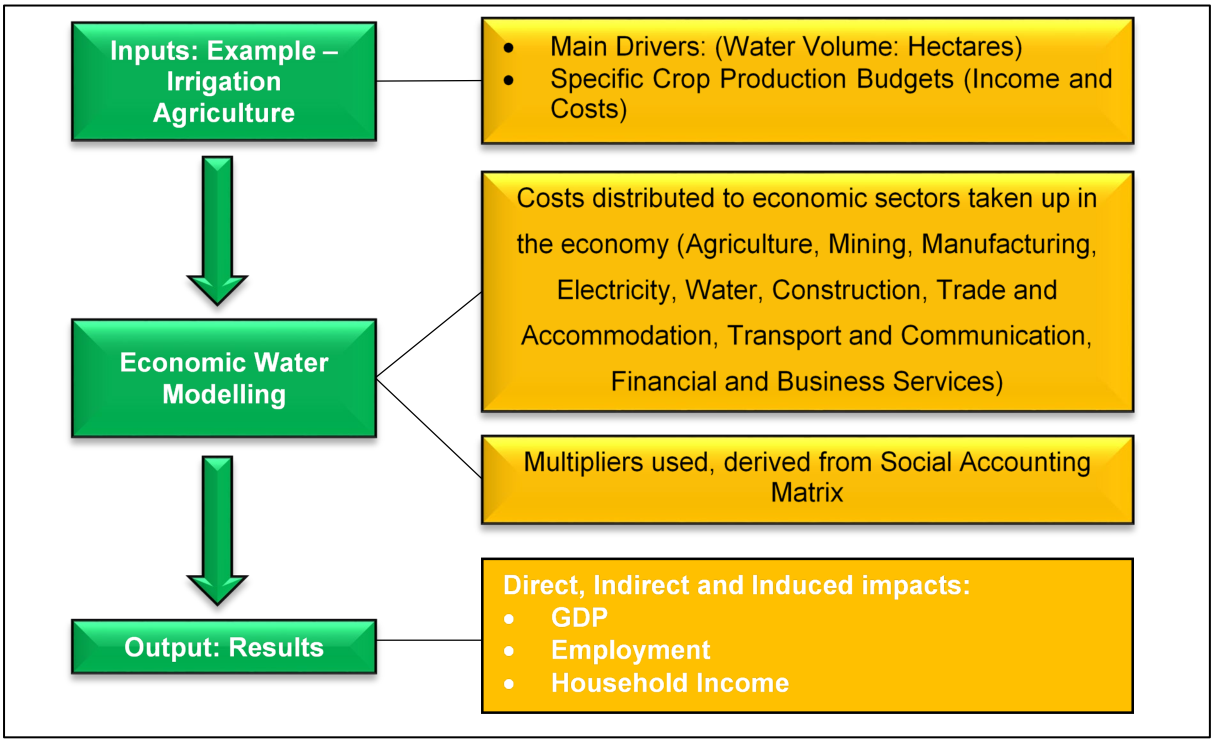

Figure 7: Schematic illustration of the WIM

The first step when calculating the macroeconomy of each of the economic regions is to identify and establish the detailed water users in terms of volume used. In the case of irrigation, the detailed areas in production are determined with the different crops produced. The model is water-driven and gives the direct and indirect/induced results for the following sectors: irrigation agriculture, commercial forestry, industries and ecotourism. The agriculture model can accommodate up to 23 different products; the representative crops were used for each case study.

The detail of the irrigation crops, the areas in hectares cultivated and the specific crop production budgets must be incorporated in the WIM to calculate the economic indicators. A group of economic multipliers are then developed to compare different water-use activities in terms of GDP per cubic metre water, employment creation (number per cubic metre) and low-income households. The different sectors of the economy include the primary, secondary and tertiary sectors that are interdependent on one another (Figure 8).

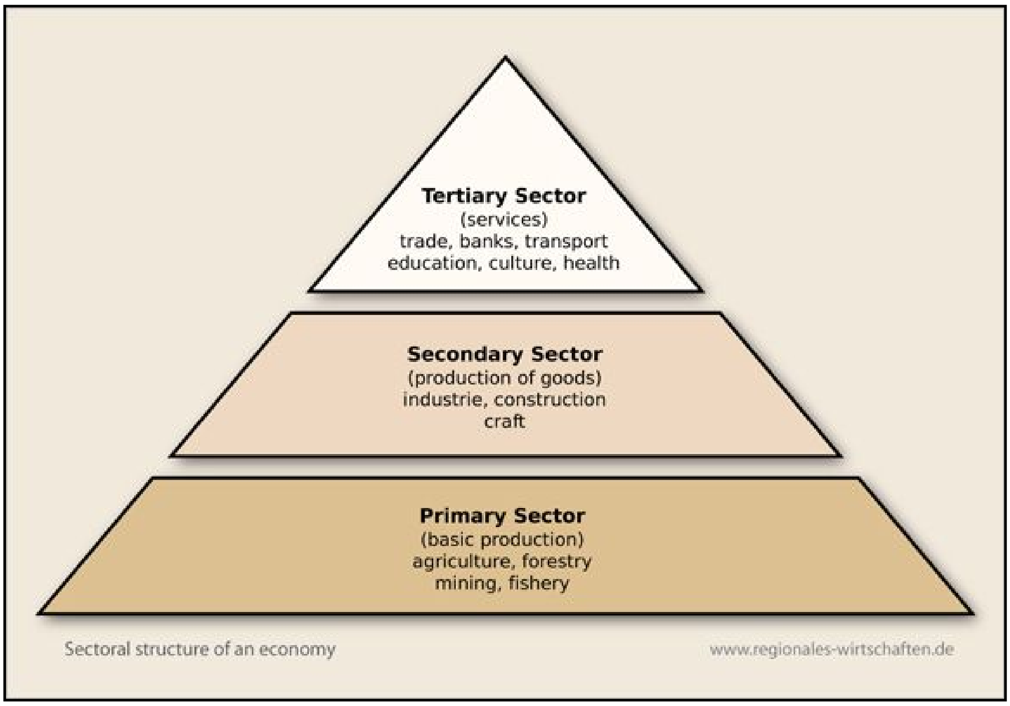

Figure 8: Different sectors of the economy

As the economy entails a number of mechanisms and linkages between sectors, distinction is made between the economic effects of direct, indirect and induced impacts used in the economic results. The latter two form part of the secondary sector. These impacts can be measured based on value added, employment, income or gross output or sales. Direct impacts are the effect expressed by the income and expenditure related to the daily operation of all the components in the production of a product in the primary sector (such as irrigation agriculture). The indirect impacts are related to economic activities that exist as a result of the components of the primary sector providing either input to or functioning on the output of the primary sector. The induced economic impacts exist as a result of the consecutive stages of the value-added process in the sectoral hierarchy indicated in Figure 8. Salaries and wages are for instance paid to the other economic sectors and result in an increased demand for consumable products, which again need to be supplied by one of the economic sectors.

Figure 7 shows the phases and components to estimate the economic impacts of each case study. The economic impact analysis is based on a number of standard economic indicators and the results are presented as the impact on GDP, capital utilisation, employment creation and household income (income distribution).

The impact on GDP reflects the magnitude of the values added to the South African economy. Value added is made up of remuneration of employees, gross operating surplus (which includes profit and depreciation) and nett indirect taxes.

The impact on capital use

For an economy to operate at a specific level of activity, investment in capital assets (such as buildings, machinery and equipment) is needed. Capital, labour and entrepreneurship are the basic factors needed for production in an economy. The effectiveness and efficiency with which these factors are combined influence the overall level of productivity/profitability processes, bearing in mind that productivity is affected by an array of factors of which appropriate technology and skill level of the labour force are two important elements.

Impact on employment creation

Labour is a key element of the production process. The study determines the number of new employment opportunities that will be created by water supply South Africa.

Impact on household income

One of the elements of the additional value added (i.e. GDP) resulting from the proposed expansion is remuneration of employees, which, in turn, affects household income. The SAM measures the magnitude of changes that will occur to both household income and spending/savings pattern.

The model drivers include the crop enterprise budget and the cost items converted to economic sectors, which are compiled in Table 10,

Table 11 and Table 12 respectively.

The different economic items to be calculated are:

$$\begin{aligned} \mathit{Gross\ Margin} &= \mathit{Gross\ Income} - (\mathit{Marketing\ costs} + \mathit{Variable\ Costs}) \\ \mathit{Nett\ Farm\ Income} &= \mathit{Gross\ Margin} - \mathit{Fixed\ Costs} \\ \mathit{Nett\ Income} &= \mathit{Nett\ Farm\ Income} - (\mathit{Yield\ on\ Capital} + \mathit{Management\ Fee}) \end{aligned}$$

The fixed costs are those associated with the general management of the farm.

Table 10: Crop enterprise budget structure (DWA, 2013)

Gross income
Costs
Variable costs
Marketing costs
Pre-harvest costs
Harvest costs
Insurance
Repairs and maintenance to fixed improvements
Administration costs
Fuel and electricity
Sundry
Nett farm income (NFI)

Table 11: Pre-harvest and harvest costs breakdown

Pre-harvest costs	**Harvest costs**
Fuel	Fuel
Implement repairs and maintenance	Implement repairs and maintenance
Casual labour	Casual labour
Land preparation	Packaging material
Seedling and seed	Transport
Fertiliser	Contractor cost
Agro-chemical	
Irrigation water and electricity	

For the input and output model as used by Statistics South Africa (Stats SA), the labour costs and intermediate costs are converted to standard economic sectors.

Table 12: Economic sector structure as used by Stats SA

Total costs (intermediate inputs and labour requirements)
Agriculture
Mining
Manufacturing
Fuel
Fertiliser
Pharmaceuticals
Other
Electricity
Water
Construction
Trade and accommodation
Transport and communication
Financial and business service
Community services
Salaries and wages: Skilled
Salaries and wages: Semi-skilled
Salaries and wages: Unskilled

The total cost is then accrued as follows:

$$Total\ cost = (Variable\ Cost\ +\ Fixed\ Cost) \times Hectares$$

Subsequently, the macroeconomic indicators can be calculated by multiplying the economic factors by the multipliers from the SAM representative of the region. Table 13 gives an example of the format.

Table 13: Format of the multipliers synthesised from the SAM

	GDP	**Labour**	**Capital**	**Low income**	**Total**
	Multiplier	**Multiplier**	**Multiplier**	**Households**	**Households**
Intermediate inputs					
Agriculture					
Mining					
Electricity					
Water					
Construction					
Trade and accommodation					
Transport and accommodation					
Financial and business services					
Community services					

	GDP Multiplier	Labour Multiplier	Capital Multiplier	Low income Households	Total Households
Primary inputs					
Salaries and wages: Skilled					
Salaries and wages: Semi-skilled					
Salaries and wages: Unskilled					
GOS					

3.4 Social Accounting Matrix

A SAM is a comprehensive, economy-wide database, which contains information on the flow of resources that takes place between the different economic agents that exist within an economy (such as business enterprises, households, government) during a given period of time – usually one calendar year. When economic agents in an economy are involved in transactions, financial resources change hands. The SAM provides a complete database of all transactions that take place between these agents in a given period, thereby presenting a snapshot of the structure of the economy for that time period. As a system for organising information, a SAM presents a powerful tool in terms of which the economy can be described in a complete and consistent way:

- Complete in the sense that it provides comprehensive accounting of all economic transactions for the entity being represented (i.e. country, region/province, city, etc.); and
- Consistent in that all incomes and expenditures are matched.

Consequently, a SAM can provide a unifying structure within which the statistical authorities can compile and present national accounts. Like the traditional input-output table, the SAM reflects the intersectoral linkages in terms of sales and purchases of goods and services, as well as the remuneration of production factors, which forms the essence of any economy's functioning. What is also of importance is that a SAM reflects economy-related activities of households in some detail. Households are responsible for decisions that have a direct and indirect effect on important economic variables such as private consumption expenditures and savings. These economic aggregates are important drivers of the economic growth processes and ultimately the creation of employment opportunities and wealth. Private consumption expenditure, for example, comprises approximately 60% of total gross final domestic spending in the economy. By combining households into meaningful categories, such as a range of income levels, the impact on the welfare of these households of a changing economic environment is made possible by the SAM.

Because of the intrinsic characteristics of the SAM, once compiled, it renders itself as a useful tool for analytical purposes. Especially, based on the mathematical traits of the matrix notations that describe its structure, a SAM can be transformed into a powerful econometric tool/model. For example, the model can be used to quantify the probable impact on the economy of a new infrastructural project such as a new power station – both the construction phase and the operational phase will be modelled. Thus apart from serving as an extension to a country's national accounts, the SAM in its model form presents many opportunities for the economic analyst to conduct rigorous policy and other impact analyses for the purpose of ensuring optimal benefit to stakeholders.

3.4.1 Application

The development of the SAM is significant as it provides a framework within the context of the International System of National Accounts in which the activities of all economic agents are accentuated and prominently distinguished. By combining these agents into meaningful groups, the SAM makes it possible to clearly distinguish between groups, to research the effects of interaction between groups, and to measure the economic welfare of each group. There are two key reasons for compiling a SAM:

- Firstly, to provide a framework for organising information about the economic and social structure of a particular geographical entity (i.e. a country, region or province) for a particular time period (usually one calendar year); and
- Secondly, to provide a database that can be used by any one of a number of different macro-economic modelling tools for evaluating the impact of different economic decisions and/or economic development programmes.

Because the SAM is a comprehensive, disaggregated, consistent, and complete data system of economic entities that captures the interdependence that exists within a socio-economic system, it can be used as a conceptual framework for exploring the impact of exogenous changes in such variables as exports, certain categories of government expenditure, and investment on the entire interdependent socio-economic system. The SAM, because of its finer disaggregation of private household expenditure into relatively homogenous socio-economic categories that are recognisable for policy purposes, has been used to explore issues related to income distribution. The SAM's main contribution in the field of economic policy planning and impact analysis is divided into two categories:

1. As a primary source of economic information

As a detailed and integrated national and regional accounting framework consistent with officially published socio-economic data, a SAM instantly projects a picture of the nature of a country or region's economy. It lends itself to both descriptive and structural analysis.

2. As a planning tool

Due to its mathematical/statistical underpinnings, it can be transformed into a macroeconometric model that can be used to:

- Conduct economic forecasting exercises/scenario building.
- Conduct economic impact analysis both for policy adjustments at a national and provincial level and for large project evaluation.
- Conduct self-sufficiency analysis, i.e. gap analysis to determine, with the help of the interindustry and commodity flows contained in the provincial SAM, where possible investment opportunities exist.
- Calculate the inflationary impacts on provincial level of price changes instigated at national level (such as administered prices and VAT).

To summarise: the SAM mechanism provides a universally acceptable framework within which the economic impact of development projects and policy adjustments can be reviewed and assessed at both national and provincial/regional levels. It serves as an extension to the official national accounts of a country's economy and, therefore, provides a wealth of additional information – especially when disaggregated to more detailed levels.

3.5 Economic Assessment

An economic analysis can be done for a river catchment including different water users to establish their impact on the economic indicators such as GDP, low household income and labour within that catchment. The macroeconomic indicators are calculated by using the WIM, which is a dynamic computerised water entitlement model customised for the irrigation sector.

How assurance of supply influences the WIM

The WIM is driven by production budgets, which are set up for each individual crop under irrigation in a certain area. These production budgets are used to calculate the labour requirements per hectare, the tons per hectare, as well as the gross income per hectare under assumption of a 100% supply of the water allocation. The percentage water supply affects the WIM and the resulting metrics by a variation of the yield of crops. This variation then leads to a new macroeconomic impact for the specific region in which the assurance of supply was introduced.

3.5.1 Crop yield response to water shortage

Some of the larger water users from a defined water resource system are often from the irrigation sector who, compared to other strategic users, are usually prioritised at a lower assurance of water supply. Consequently, they operate their businesses at a larger risk of non-supply (of water) and effectively they also face the risk of potentially having a reduction in crop production and quality. It is therefore important to know what impact a reduced water supply has on crop yield to ultimately determine the direct and indirect economic implications the risk of non-supply has on the irrigation sector. The execution of the WIM is based on the crop yield production, which is influenced by a variation in water supply.

The Food and Agriculture Organization of the United Nations (FAO) has done a fair amount of research on crop yield response to water. They have developed a herbaceous crop simulation model named AquaCrop (a product resulting from the collaboration and consultation among crop specialists and practitioners worldwide).

FAO (2012: 6) addresses the relationship between crop yield and water use with the following equation:

$$\left(1-\frac{Y_a}{Y_x}\right)=K_y\left(1-\frac{W_a}{W_c}\right)$$

Where:

- Y_x is the current yield in the study areas
- Y_a is the actual yield after a water reduction
- K_y is the yield response factor
- W_a is the percentage water available after a change in water
- W_c is the current water available in the study area

The above equation is a water production function and can be applied to all agricultural crops (FAO, 2012: 6). To obtain the actual yield, the equation can be rewritten as:

$$Y_a=\left[1-K_y\left(1-\frac{W_a}{W_c}\right)\right]Y_x$$

The yield response factor represents the link between water use of a crop and the production. To simplify the simulation of the WIM, the total yield response factor is used. The relationship in the response factors can be explained as follows:

Table 14: Response factor relationship

$K_y > 1$	Crop response is very sensitive to water deficit with proportional larger yield reductions due to a reduction in water.
$K_y < 1$	Crop response is tolerant to water deficit with less than proportional larger yield reductions due to a reduction in water.
$K_y = 1$	Crop response is directly proportional to a reduction in water use.

Table 15 lists the yield response factors (K_y) as applied in the estimated yields. In cases where exact crop yields were not available, crops similar to those factors were used.

Table 15: Crop yield response factors

Crop	Total yield response factors (K_y)
Maize	1.25
Table grapes (vine)	0.85
Dry beans	1.15
Pastures	1.1
Summer vegetables (cucurbits – butternut)	1.1
Winter vegetables (brassicas – cabbage)	0.95
Industrial tomatoes	1.05
Fresh tomatoes	1.05
Potatoes	1.1
Wheat	1.05
Macadamias	0.7
Citrus (Valencia)	1.1
Bananas	1.3
Avocadoes	1.1
Litchis	1.1
Mangoes	1.2
Citrus (grapefruit)	1.1
Wine grapes (white)	0.85
Dry fruit (vine)	0.85
Sugar cane	1.2

It is important to consider the different growth stages of various crops, which result in different water requirements throughout the growing season. Therefore, crop-specific yield response factors also change over the growing season. Consequently, the effect water stress has on crop yield response is more severe during the flowering and yield formation stages than the effect it has during the ripening and vegetative phases. The latter depends on the crop's ability to recover from water stress in the preceding growing stages. Figure 9 shows the linear water production functions for maize subjected to water stress per individual growth period.

> *"The steeper the slope (i.e. the higher the K_y value), the greater the reduction in crop yield for a given reduction in evapotranspiration (ET) because of water deficits in the specific period" (FAO, 2012).*

Therefore, when making water allocation decisions in times of limited water availability, it is important to ensure that the crop water requirements during the critical crop-growing stages are fully met instead of distributing the allocation equally over the whole growing season.

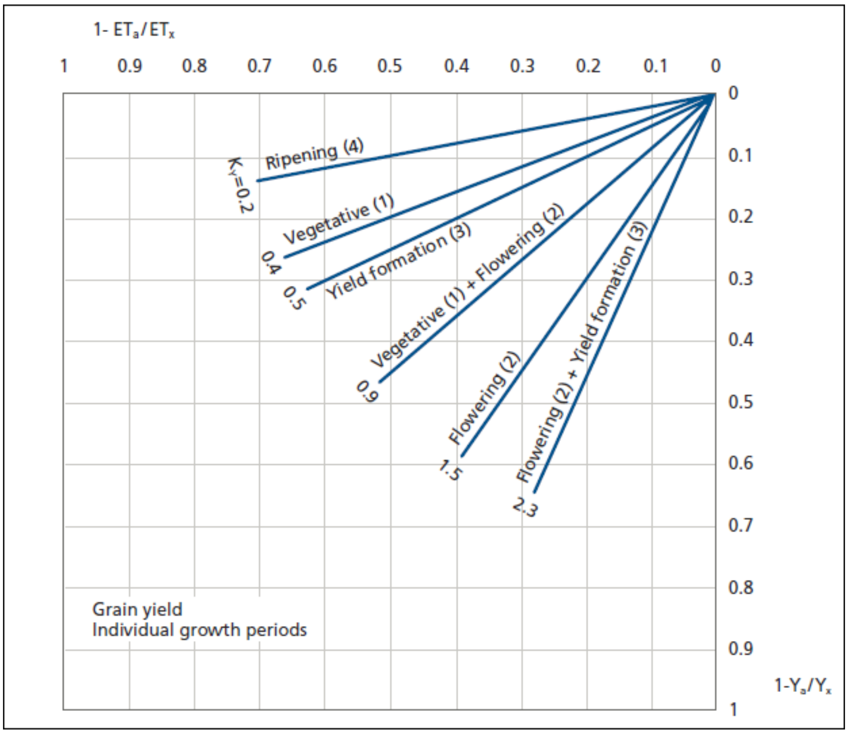

Figure 9: Water production functions for maize in relation to water stress (FAO, 2012)

Figure 10 simulates various potato yields against irrigation water applied for an average, good and bad climatic year of which the latter refers to a drier year. Varying irrigation requirements for over 25 years' climate data have been used to simulate the potato production.

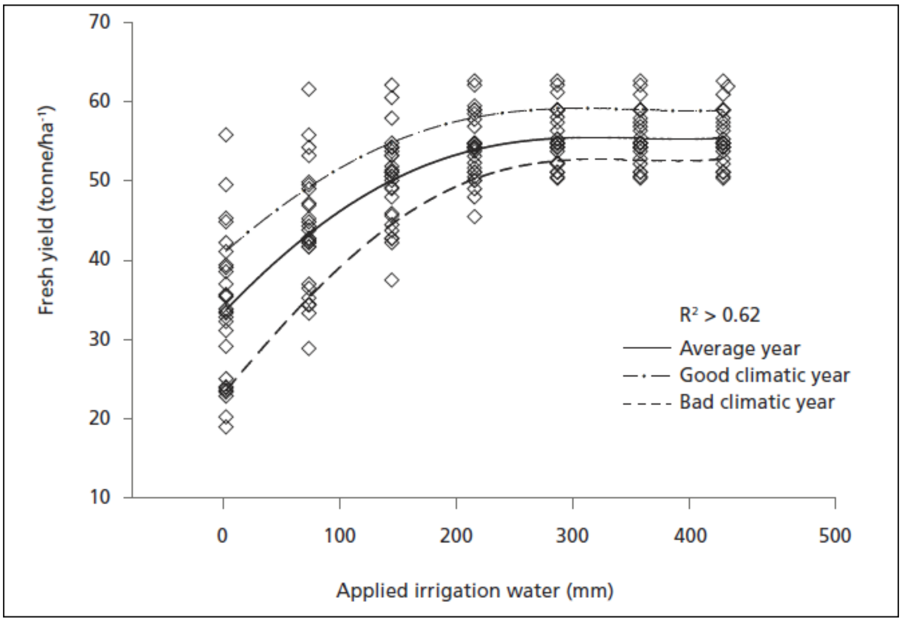

Figure 10: Yield response curves for potatoes in three different climatic years (FAO, 2012)

Such crop production simulations can be applied in economic analyses to provide decision support on how to maximise financial gain under given conditions by specifically determining the optimum irrigation application.

Figure 11 and Figure 12 show the resulting yield that each crop has with a variation in water supply when applied in the WIM. There is variation among crop yields, which results in different impacts on the economic indicators in different regions.

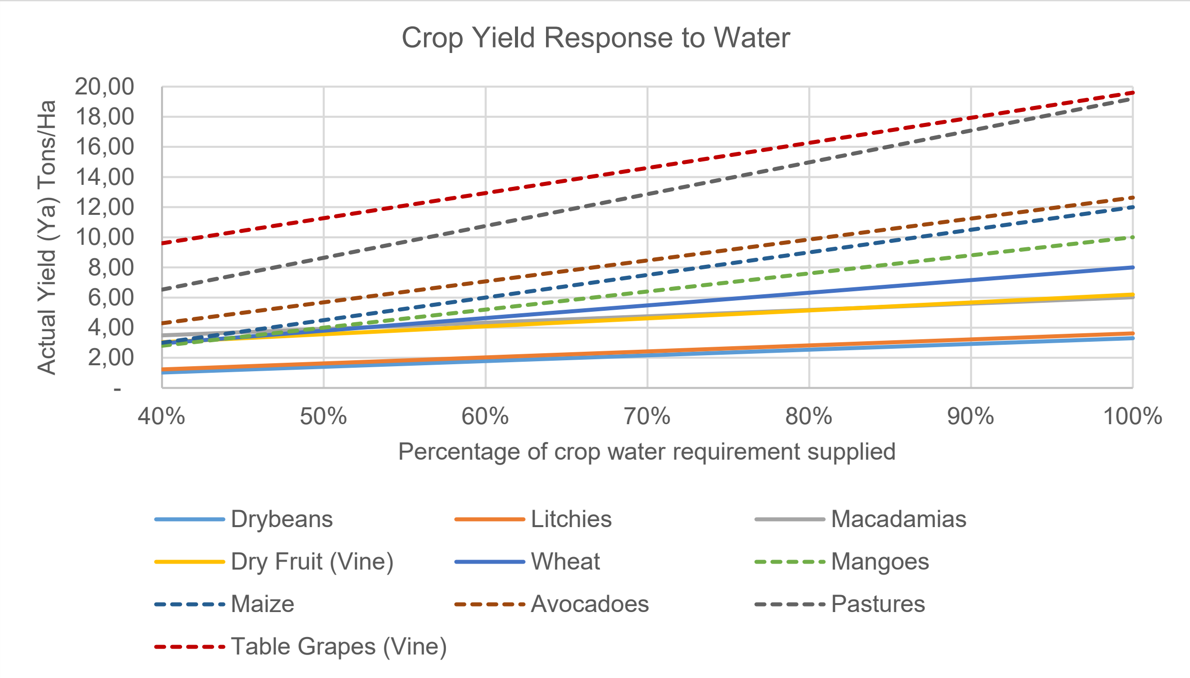

Figure 11: Crop yield response with current yields less than 20 ton/ha (Conningarth, 2016)

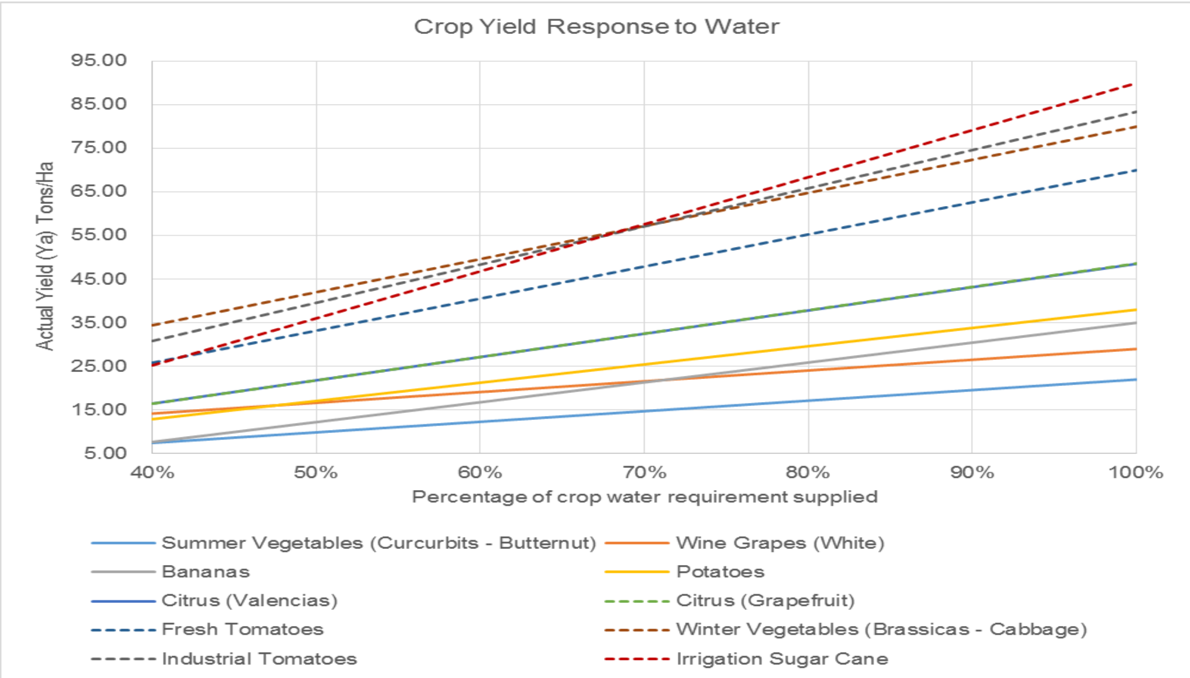

Figure 12: Crop yield response with current yields less than 100 ton/ha (Conningarth, 2016)

Figure 12 shows that irrigated sugar cane demonstrates a high sensitivity to a water deficit relative to other crops. Since irrigated sugar cane represents a substantial portion of the total hectares in the Mhlathuze System, for example, reduction in water availability has a significant economic impact. As indicated by these graphs, current information applied in WIM assumes the crop yields are linear to the reduction in water supply. This linear relationship must be adapted to take the marginal yield decreases with an increase in water supply into account. The opposite is also true: marginal reduction in yield increases as the water supply decreases. This can be seen in Figure 13 for the empirical study done on irrigated maize in Garden City in Kansas for years 2005 to 2011 (Rogers, 2015).

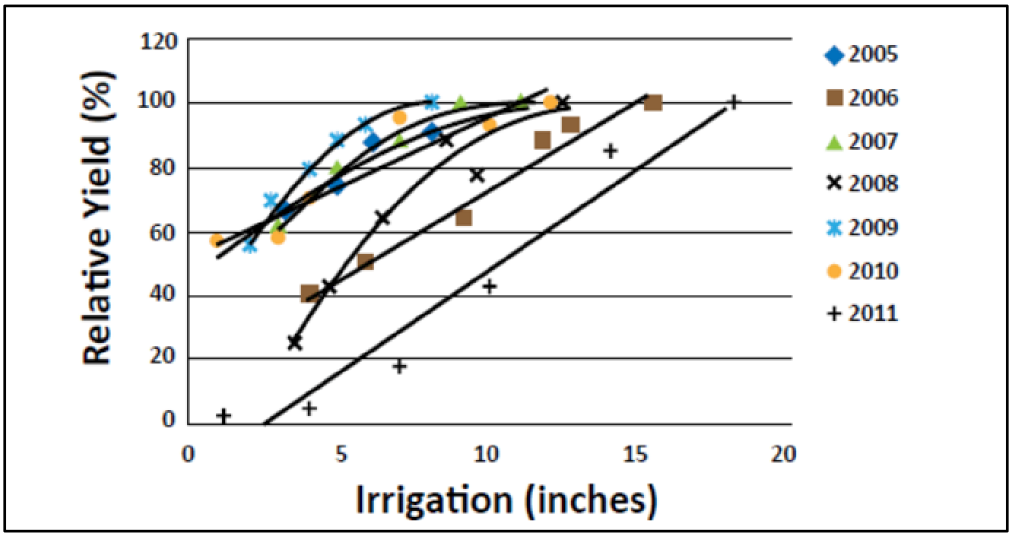

Figure 13: Relative corn yield as related to irrigation amount by year (Rogers, 2015)

There is some form of non-linearity in each year in the fitted curve (Figure 13). Regression analysis, as can be seen in Figure 14, has an equation of the form:

$$Yield_{crop} = -0.285(I)^2 + 8.92(I)$$

where the irrigation *(I)* is in inches.

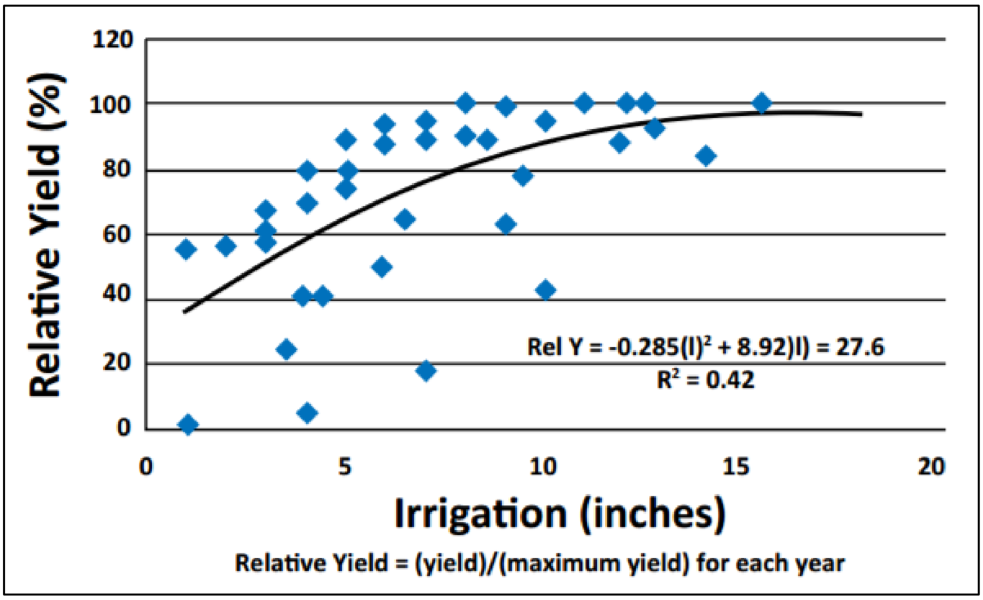

Figure 14: Fitted curve of relative corn yield as related to irrigation (Rogers, 2015)

The quadratic equation shows that there is indeed a marginal reduction in yield as irrigation increases. The negative coefficient (-0.285) related to the quadratic term $(I)^2$ shows that the increase in relative yield is less than linear because of the downward trend of the quadratic term, which will eventually have a downward effect as is expected of oversaturated soils.

Wichelns (2014) shows that several other authors have incorporated a quadratic term in their empirical studies of production functions. Onion production in Nigeria can be expressed as:

$$Yield_{crop} = -14.88 + 0.131\,(AW) - 0.0001(\,AW)^2,$$

where the yield of the crop is in tons per hectare and AW refers to the applied water in millimetre. In each of these cases, there is a negative coefficient related to the quadratic term, which shows the marginal decrease in yield.

To conclude, the current linear model incorporated in the WIM is not sufficient: a quadratic term needs to be incorporated at a later stage to have a more realistic economic parameter and to avoid exaggerating the reduction in water supply in the event of an oversupply, or to understand it in the case of undersupply. This will improve the estimates of the economic impact of changes in water supply. For this research study, however, the linear model will be used.

3.5.2 Example of effect of risk of non-supply (water) on GDP

Suppose that the reduction in water supply causes a 20% decrease in the yield of an amount of hectares of maize from a specific region. This reduction in hectares, combined with the sectoral economic multipliers for that region, will lead to a reduction in GDP (R millions) as shown in Table 16.

Table 16: Effect of risk of non-supply of water on GDP

Economic multipliers	GDP	
	Current situation (full water supply)	**New situation (reduced water supply)**
Intermediate inputs		
Agriculture	3.84	3.07
Mining	–	–
Manufacturing	11.28	9.03
Electricity	3.25	2.60
Water	0.44	0.35
Construction	1.34	1.07
Trade and accommodation	–	–
Transport and communication	1.84	1.47
Financial and business services	4.57	3.66
Community services	–	–
Primary inputs		
Salaries and wages: Skilled	0.32	0.26
Salaries and wages: Semi-skilled	0.28	0.22
Salaries and wages: Unskilled	0.20	0.16
GOS	5.17	4.13
Indirect and induced impact	R32.55	R26.04
Plus: Direct impact added where necessary	R22.36	R17.89
Total impact	**R54.91**	**R43.93**

This reduction is due to the SAM multipliers and the interdependence of the economy. It can be seen that there are reductions in all relevant sectors. The above represents the effect of a reduction in hectares of one crop in one of the three regions for one iteration of a simulation for a period in time on the GDP. This must be repeated for all crops in the relevant area to calculate the total impact of a reduction in water supply.

3.5.3 Present values of economic indicators

The difference between benefits and costs (the nett benefit) in the specified year is discounted to the present by using a social discount rate. The discounted sum of all these nett benefits over the economic project life is defined as the nett present value (NPV). In terms of the terminology set out above:

$$NPV = \frac{\sum b_t}{(1+i)^t} - \frac{\sum c_t}{(1+i)^t}$$

where *b* = benefits, *c* = production costs, *t* = time, *i* =

The criterion for the acceptance of a project is that the NPV must be positive; in other words, funds will be voted for a project only if the analysis produces a positive NPV. Where a choice has to be made between mutually exclusive projects, the project with the highest NPV will be chosen since it maximises the nett benefit to the community. Similarly, the NPV of various crops will be analysed to determine the economic effect of a reduction in water supply to the different crops. This will give an indication to which crop types water supply should be restricted first in order to reach an economic optimal decision.

3.6 Process Analysis

If the analysis is undertaken in the WRYM only, the output files to be used are known as the `plt.out` and the `dem.out` wherein the monthly volumes of demand and supply for each of the demand channels are summarised. These volumes are then converted to annual volumes, and the proportion of the difference between the total system demand and available system supply is multiplied with the factor defined in the user priority criteria table. It is expressed as a percentage of the water supply curtailment to the irrigation agricultural sector, which is used as input to the WIM. Figure 15 shows this process.

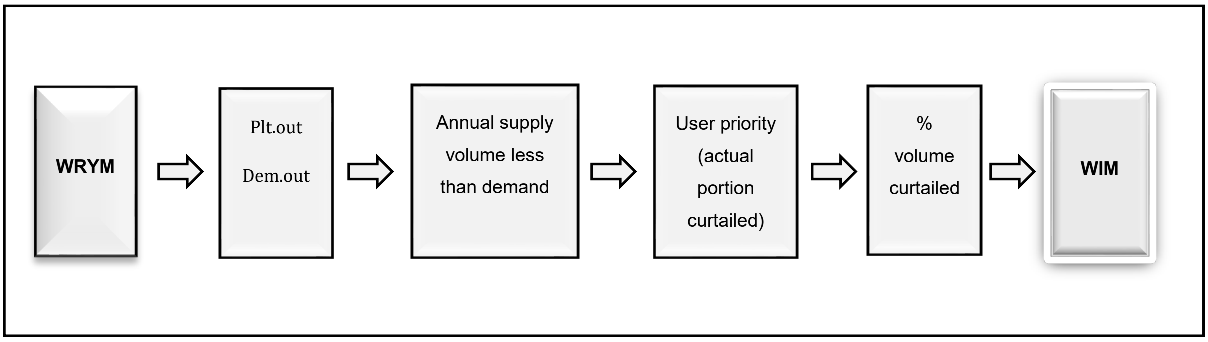

Figure 15: Procedure using the WRYM

If the WRPM is used for the analysis, an output file known as the `sys.out` is created from where the factor of the level of curtailment is obtained. This factor is then multiplied with the curtailment factor specified in the user priority criteria and expressed as a percentage of the total water supply curtailment to the agricultural sector, which is used as input to the WIM. This process is indicated in Figure 16.

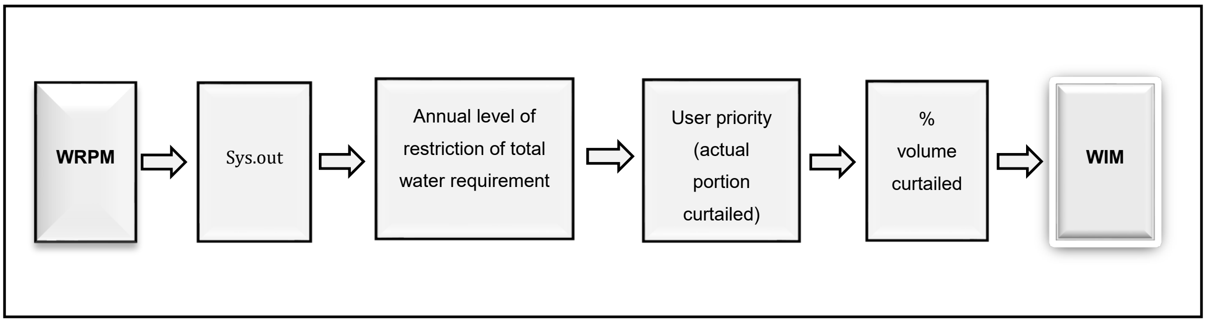

Figure 16: Procedure using the WRPM

Figure 17 shows a schematic representation of the overall process showing the models to be applied, the information flow linkages and the key results being envisaged from the various analysis steps. Each element in the analysis process is labelled by an alphabetic letter in brackets. The arrows indicate the flow of information (data) between elements. It is envisaged that there will be two information flow paths as indicated by the red and blue arrows respectively (see explanation in subsequent text). It is also foreseen that multiple scenarios will be analysed as reflected by the S1, S2 … and Sx labels. Descriptions of each of the process elements are provided next in order of the sequence in which they will be applied.

A. User priority and risk criteria

The user priority and risk criteria definition or table is the primary input data set that will be varied in the scenario analyses. The objective is to evaluate the economic implications of alterative settings of the user priority table with the aim to find the optimum or most suitable set of parameters.

B. WRPM

The simulation of the water resource systems will be undertaken with the WRPM and drought restrictions will be modelled by applying the embedded allocation algorithm. The simulations will be carried out for 1000 stochastic sequences considering both constant development and projections analyses of the configured network systems. The output from the WRPM analyses for use in the further steps will be times series of drought restriction levels.

C. Risk analysis (results from WRPM)

The output from the WRPM risk analysis will be time series of drought restriction levels (for 1000 stochastic sequences) as determined by the WRPM at the selected annual or bi-annual decision dates in the simulation period. This output relates directly to the scenario's user priority definition (A). The restriction level scale represents the volumetric magnitude of the restriction for each of the risk levels in the respective user groups.

Figure 18 is an example of the `sys.out` file as output from the WRPM for a 1000 sequences.

D. Water impact model

The WIM will be adapted to use the risk analysis time series and produce the required economic indicators. The WIM is used to determine the economic impact of crops directly related to the irrigation agriculture sector. The input to the WIM comprises water volumes supplied to the various crops as well as the specific production budgets for each crop. The production budgets are made up of variable costs and fixed costs in order to determine the gross income for each of the crops. It also gives the labour requirements per hectare, as well as the current yield at 100% water supply.

The gross income is modelled to simulate the impacts that are distributed through the economy by means of multipliers derived from the South African National SAM.

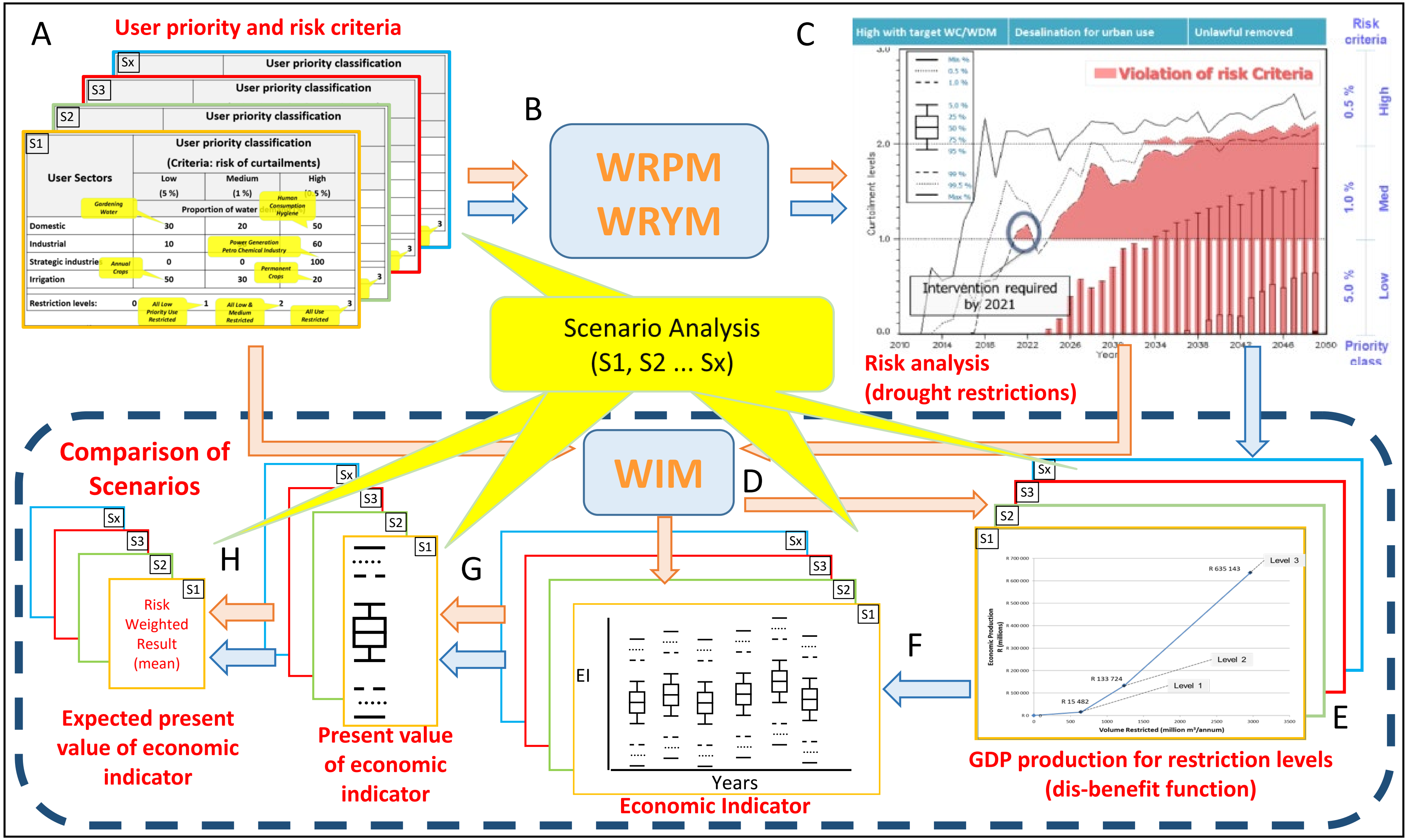

Figure 17: Schematic representation of the proposed analysis processes

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ACRES INTERNATIONAL LIMITED        MULTI-PURPOSE/MULTI-RESERVOIR SIMULATION PROGRAM        YYYYMMDD     hh:mm:ss          PAGE    1

                            Scen B 1/05/2016 MAY: Based on WRP ORASECOM PHASE 3 ORS (FEBRUARY 2015)
                            INCL.CORR IRR BLOCKS(ISSUE WITH CURT TYPE 4)AND VAAL AND BLOEM SYSTEM UPDATES(FR
                            PD 2012 DEV: BASE SCEN (ADJ MINE DEW+RE-USE;RW HIGH; ESKOM BASE;REDUCED PUMPING)

 STOCHASTIC SHORT-TERM PLANNING RESULTS                  RESOURCE ALLOCATION LEVELS                  SEQUENCE S  1

          SYSTEMPK           SYS VOL         FSV         DSV     MONTH

    YEAR

    2015    0.0000    0.0000    6960.7942  11267.6014    942.6680       MAY
    2016    0.0000    1.1629    4492.6538  11267.6014    942.6680       MAY
    2017    0.0000    0.0000    7363.8679  11267.6014    942.6680       MAY
    2018    0.0000    0.0000    9279.1484  11267.6014    942.6680       MAY
    2019    0.0000    0.0000    9868.0462  11267.6014    942.6680       MAY
    2020    0.0000    0.0000   10113.5786  11267.6014    942.6680       MAY
    2021    0.0000    0.0000   10472.8601  11267.6014    942.6680       MAY
    2022    0.0000    0.0000   10641.9828  11267.6014    942.6680       MAY
    2023    0.0000    0.0045    8529.7683  11267.6014    942.6680       MAY
    2024    0.0000    0.8228    7898.9387  11267.6014    942.6680       MAY
ACRES INTERNATIONAL LIMITED        MULTI-PURPOSE/MULTI-RESERVOIR SIMULATION PROGRAM        YYYYMMDD     hh:mm:ss          PAGE    2

                            Scen B 1/05/2016 MAY: Based on WRP ORASECOM PHASE 3 ORS (FEBRUARY 2015)
                            INCL.CORR IRR BLOCKS(ISSUE WITH CURT TYPE 4)AND VAAL AND BLOEM SYSTEM UPDATES(FR
                            PD 2012 DEV: BASE SCEN (ADJ MINE DEW+RE-USE;RW HIGH; ESKOM BASE;REDUCED PUMPING)

 STOCHASTIC SHORT-TERM PLANNING RESULTS                  RESOURCE ALLOCATION LEVELS                  SEQUENCE S  2

          SYSTEMPK           SYS VOL         FSV         DSV     MONTH

    YEAR

    2015    0.0000    0.0000    6960.7942  11267.6014    942.6680       MAY
    2016    0.0000    0.0000    7302.0424  11267.6014    942.6680       MAY
    2017    0.0000    0.1647    5268.2247  11267.6014    942.6680       MAY
    2018    0.0000    0.7911    5147.5052  11267.6014    942.6680       MAY
    2019    0.0000    0.4624    4016.6850  11267.6014    942.6680       MAY
    2020    0.0000    0.9030    4632.7590  11267.6014    942.6680       MAY
    2021    0.0000    1.3857    3469.5161  11267.6014    942.6680       MAY
    2022    0.0000    2.3467    2827.7846  11267.6014    942.6680       MAY
    2023    0.0000    0.0000    6933.8712  11267.6014    942.6680       MAY
    2024    0.0000    0.1652    6352.3503  11267.6014    942.6680       MAY
```

Figure 18: Example of `sys.out` file output from WRPM

The WIM thus yields direct, indirect and induced impacts for both GDP and employment. Figure 19 shows an example of the WIM input based on 57% less than the baseline water being supplied.

Analysis Information	Current Situation											
Main system	**Orange River**											
Sub-system	**Orange River**											
Scenario-Option	**1.11**											
Baseline	**100%**											
% Assurance change	**57%**											
	Economic Indicators											
	Agriculture											
	2016 Numbers, Prices				**Projected Impact of water restrictions**							
		Surplus Value (Rand Mil)	**GDP (Rand Mil)**			**Employment (Numbers)**			**Capital (Rand Mil)**	**Household Income (Rand Mil)**		
		Direct	**Direct**	**Indirect and Induced**	**Total**	**Direct**	**Indirect and Induced**	**Total**	**Total**	**Total**	**Medium**	**Low**
	Maize	R 358	R 516	R 428	R 945	10 115	2 519	12 634	R 1 445	R 444	R 300	R 144
	Soya Beans	R 44	R 44	R 13	R 58	73	74	148	R 50	R 12	R 6	R 6
	Dry Beans	R 45	R 45	R 13	R 57	393	70	463	R 48	R 27	R 20	R 7
	Industrial Tomatoes	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Fresh Tomatoes	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Potatoes	R 371	R 376	R 143	R 520	2 872	849	3 721	R 509	R 282	R 203	R 79
	Summer Vegetables	R 82	R 86	R 30	R 116	1 469	159	1 628	R 109	R 71	R 48	R 22
	Winter Vegetables	R 0	R 0	R 0	R 0	782	-	782	R 0	R 0	R 0	R 0
	Wheat	R 0	R 0	R 0	R 0	2 346	-	2 346	R 0	R 0	R 0	R 0
	Lucerne	R 1 182	R 1 182	R 332	R 1 514	15 712	1 846	17 558	R 1 255	R 615	R 462	R 153
	Sugar Cane Irr	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Bananas	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Grapes Fresh	R 1 161	R 1 167	R 336	R 1 503	8 173	1 873	10 046	R 1 264	R 301	R 152	R 149
	Grapes Wine	R 307	R 307	R 86	R 393	2 000	479	2 480	R 326	R 218	R 157	R 61
	Grapes Dry	R 1 037	R 1 048	R 301	R 1 348	10 405	1 672	12 077	R 1 136	R 536	R 401	R 135
	Macadamias	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Citrus Valencias	R 1 563	R 1 563	R 439	R 2 002	11 766	2 442	14 208	R 1 660	R 1 044	R 766	R 278
	Citrus Grapefruit	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Avocadoes	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Litchies	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Decidous Fruit	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Palm Dates	R 178	R 198	R 63	R 261	240	347	587	R 233	R 111	R 83	R 28
	Mangoes	R 0	R 0	R 0	R 0	-	-	-	R 0	R 0	R 0	R 0
	Total	**R 6 327**	**R 6 533**	**R 2 183**	**R 8 716**	**66 347**	**12 331**	**78 678**	**R 8 034**	**R 3 661**	**R 2 600**	**R 1 061**

Figure 19: WIM input

E. GDP versus restriction relationship

It is foreseen that a further derived output from WIM could be a relationship (curve) between the level of restriction and an economic indicator such as GDP. The outcome of the research (scenarios simulations and sensitivity analysis) will indicate the variables influencing this relationship and if the application thereof (once it has been determined for a water resource system by WIM) can be applied as substitute for the full WIM for water resource assessments given adherence to certain constraints. An example of such a relationship is shown in Figure 20.

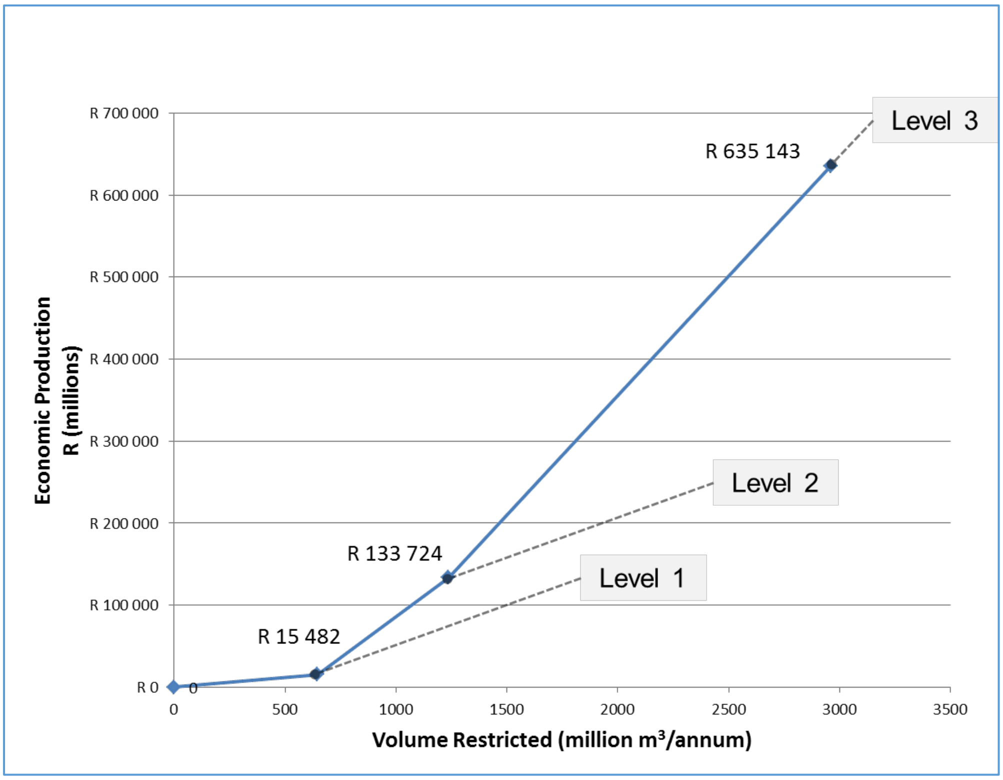


Figure 20: GDP vs. volume for indicated restriction levels

F. Economic indicators

The WIM will produce annual time series of economic indicator(s). The output (1000 sequences) will be graphically presented as probability distribution plots (box plots) for inspection and comparison between the scenarios. Detail evaluation of the input and output for selected single sequence time series will be carried out to verify the results from the WIM. Typical checks will entail determining if the expected variations (changes) do occur given the characteristics of the simulated restriction time series. The WIM gives outputs in the form of GDP and employment in the economic regions of the study areas. The impact on GDP reflects the magnitude of the values added to the regional and wider economy from activities using the water.

Labour is a key element of the production process, especially in agriculture. WIM estimates the number of employment opportunities supported by the use of the water versus the reduction in employment due to a reduction in water available for irrigation. These employment opportunities are broken down into those created directly by the irrigation sector, and those created indirectly and induced throughout the broader economy.

G. Present value of economic indicator

In order to account for the time value of a time series of monetary metrics, the present value of each of the 1000 sequences will be calculated to provide a probability distribution of the present value for each scenario. This metric will ensure the proposed method can be used to evaluate time-dependent decisions, such as whether moderate drought restrictions should be implemented straightaway or whether they can be delayed until later when more severe restrictions are implemented at a certain risk.

The present value of the GDP will be used to have one single comparable value for the economic output of the WIM for all simulated sequences. This process is shown in Figure 21 where the values over the analysis period (15 years) are discounted to a present value for each of the 1000 simulations.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1											SEQUENCES 1 - 1000									
2	Year1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Year2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Year3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Year4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Year5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Year6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Year7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Year8	865.4725	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Year9	1955.583	879.0936	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Year10	2951.262	965.8409	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Year11	918.3931	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Year12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2307.68
14	Year13	0	0	0	0	0	0	882.6737	0	0	0	0	0	0	0	0	2367.36	0	0	0
15	Year14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3434.105	0	0	0
16	Year15	0	0	0	0	0	0	0	0	0	0	882.5801	0	0	0	0	1019.982	0	0	0
17																				
18											NPV									
19	Discount rate 1	3832.282	1059.655	0	0	0	0	413.8319	0	0	0	368.2698	0	0	0	0	3054.422	0	0	1146.846
20	Discount rate 2	3206.755	887.1369	0	0	0	0	324.5573	0	0	0	278.226	0	0	0	0	2361.193	0	0	916.4116
21	Discount rate 3	2692.838	745.195	0	0	0	0	255.6791	0	0	0	211.2826	0	0	0	0	1834.223	0	0	735.298
22																				

Figure 21: Analyses matrix in the ASM

H. Expected value (mean) of economic indicator

This entails calculating the mean of the 1000 present values to serve as single metric output: the expected present value for a scenario. For example, the loss in GDP will be used to have one single comparable value for the economic output of the WIM for all of the simulated sequences. Furthermore, the calculation of the mean of the 1000 present values will be discounted at either 0%, 6% or 8%.

The Water Research Commission (WRC) publication TT598/14, *A Manual for Cost Benefit Analysis in South Africa with Specific Reference to Water Resource Development* (Mullins, 2014:63–70) provides a detailed analysis of the theoretical background of selecting an appropriate discount rate. In short the discount rate can be defined as:

> *"The discount rate is the rate of return used in a discounted cash flow analysis to determine the present value of future cash flows."*

The official rate as proposed by the Reserve Bank for an economic price calculation in South Africa is 8%, while 12% is used in the case of financial priced models. The effect of this is that 8% is used for proposed investments that make no provision for inflation and 12% is applied to calculations where inflation is taken into account. For sensitivity analysis, different rates are used. The Environmental Lobby is asking for a 4% to 6% rate. Many countries have changed the rate over time: before 1992, the United States of America used 10%; after 1992, it used 7%. The Peoples Republic of China uses 8% for short- and medium-term projects and a rate lower than 8% for long-term projects.

3.7 Analyses Techniques

A key activity of the research entails developing the required data (input and output) handling and calculation automation software utilities (algorithms) to sequentially perform each of the analysis steps shown in Figure 17. The software utilities or scripts will be developed in Visual Basic for Excel™, which allows easy linkage to WIM (a Microsoft Excel™-based model). Existing text file processing methods that are available to manipulate the output of the WRPM will be used.

Figure 22 illustrates the interface of the ASM, which links the output from the `sys.out` file with the WIM. Option 1 entails a linear relationship executed outside the WIM expressing the GDP loss in monetary value against the various levels of curtailment. Option 2 entails an interpolation process where the restriction level factors in the `sys.out` file are multiplied with the user curtailment proportions (as defined in the user priority classification for the given scenario) and expressed as a percentage input of water supply in the WIM (see Figure 19). At various percentages of water supply, differences in economic indicator values are obtained. This process is automated per scenario for the number of planning years and sequences specified for the analysis. The results are written to a sheet as indicated in Figure 21 to which the various discount rates (specified in (2b), Figure 22) are applied to find the present value.

To ease the interpretation of the results, the present values are ranked and sorted against the percentiles shown at (d) in Figure 22**,** which will express the probability of the present value over the given time period to be at a specific value once plotted on box and whiskers plots. The present values at the different discount rates and percentiles for the selected scenario and specific economic indicator are given as output in (2c) (Figure 22).

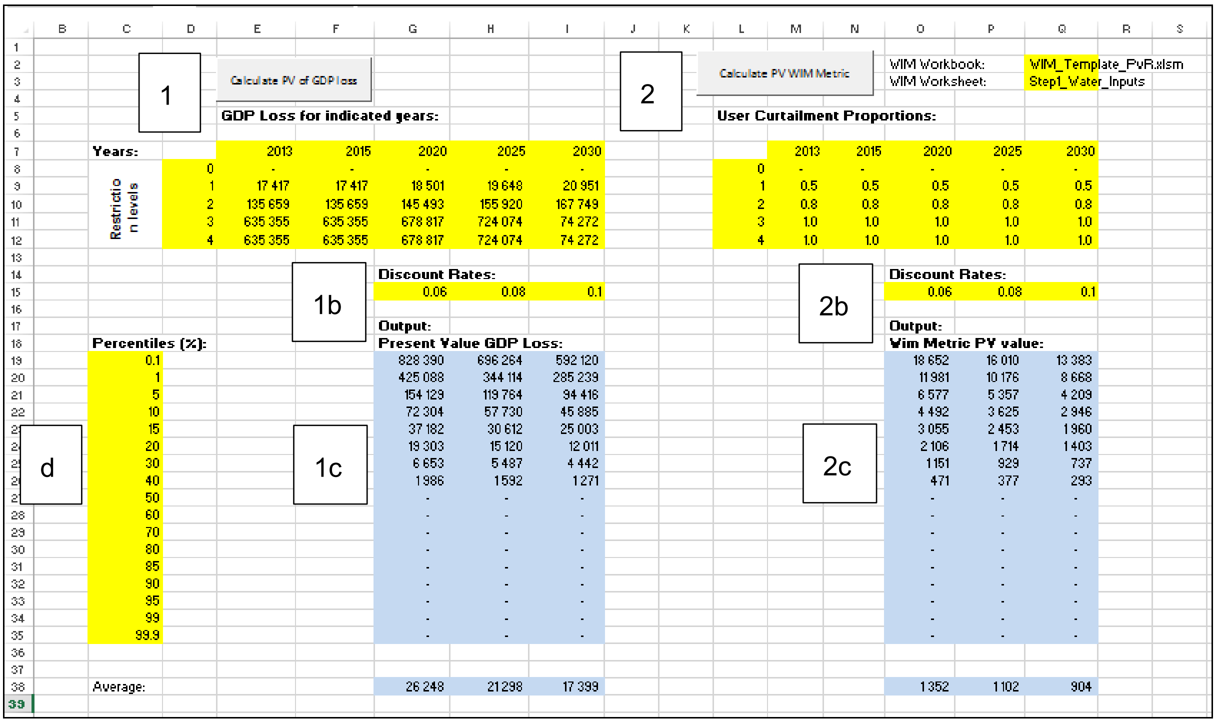


Figure 22: Interface of the ASM in Excel™

3.8 Farm Production Model

The farm production model is designed to determine if the farmer will be able to continue farming on a sustainable level despite the curtailment of water supply for irrigation crops.

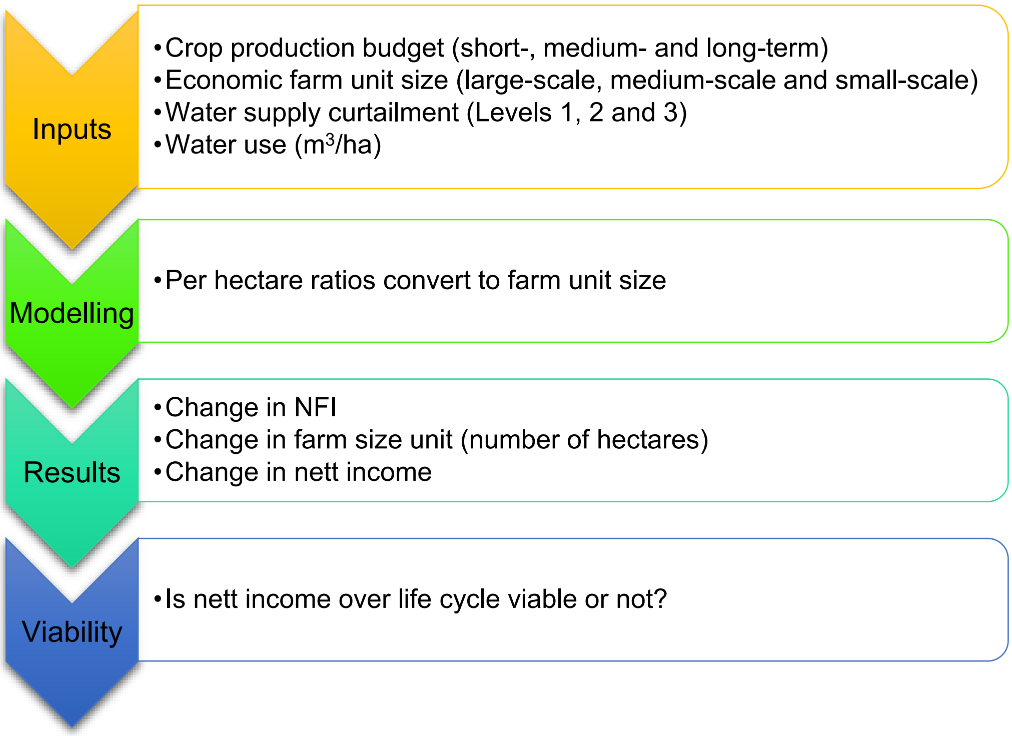


Figure 23: Farm production model

Table 17: Viability results in the farm production model

Viable at 20% curtailment				
Life cycle	**Crops**	**Large scale**	**Medium scale**	**Small scale**
Short term	Maize	**Yes**	**Yes**	**No**
	Soya beans	**No**	**No**	**No**
Medium term	Lucerne	**Yes**	**Yes**	**No**
	Sugar cane	**Yes**	**Yes**	**Yes**
	Bananas	**Yes**	**Yes**	**Yes**
Long term	Mangoes	**Yes**	**Yes**	**No**
	Deciduous fruit	**Yes**	**Yes**	**Yes**
	Palm dates	**No**	**No**	**No**

4 DESCRIPTION OF THE CASE STUDIES

4.1 Rationale

South Africa is a semi-arid country with an average annual rainfall of 608 mm (SAWS, 2016). The country faces many water resource management challenges. The challenge lies mainly in supplying the ever-growing demands of the various water user sectors equitably from existing water resources. The annual total rainfall for South Africa for the 12 months from January 2015 to December 2015 was the lowest annual total since 1904 (SAWS, 2016). Consequently, the drought index for South Africa indicated mild to severe drought conditions over most of the country. The lower rainfall was a result of a relatively large El Niño, which was comparable to the very significant events of 1982/1983 and 1997/1998 (SAWS, 2015).

A country can be classified as water-scarce or not by looking at its renewable water resource. If the renewable water resource is below 1000 m^3/person per year, the country is considered water-scarce. If the renewable water resource is above 1000 m^3/person per year but below 1700 m^3/person per year, the country is considered water-stressed. South Africa has a renewable water resource of 1048 m^3/person per year; therefore, it is a water-stressed country ranked significantly below the global average of 8210 m^3/person per year (Haggard, 2015).

Water use in South Africa (and other countries) is dominated by the agricultural sector taking up approximately 60% of the country's total use. The agricultural sector contributes about 7% to formal employment and 3% to GDP. The energy sector uses only 2% of the water but contributes approximately 15% to South Africa's GDP. Up to 250 000 jobs are created through the energy sector, which indicates its strategic importance. The urban and rural use of water constitutes approximately 18% and 4% respectively of the total usage, and mining 5% of the total usage. Commercial forestry plantations, which reduce run-off into rivers and streams, account more or less 3% of water used. Water transfers out of the country is in the order of 1% (DWA, 2013e).

The total water required for the production of platinum group metal is in the order of 806 161 m^3/ton and the financial value for the volume of water is equal to R686.00/m^3. When compared to crop production in the agricultural sector, cloves (one of the largest consumers) require up to 56 429 m^3/ton whereas tomato production are among the smaller water users requiring 117 m^3/ton. The agricultural crop with the highest financial value per cubic metre of water used for production is grapes at R250.31/m^3. This information can be used in times of drought when decisions need to be made on how to distribute water equitably within the catchment (Haggard, 2015).

It has been an ongoing challenge in South Africa to allocate water equitably – especially since the promulgation and implementation of the NWA in 1998. Allocating water among competing user sectors is highly influenced by understanding water's social, economic and ecological value. In addition, there is limited fresh water available for further development, which emphasises the importance of setting out clear priorities for allocating water. This allocation process is the responsibility of chief water resource managers; in the RSA, it is the DWS (custodian of the water) and the upcoming catchment management agencies (CMAs). The National Water Resource Strategy 2 (NWRS2) sets out five priorities in Table 18 that must give effect to allocations that promote equity:

Table 18: Allocation priorities set in NWRS2 (DWA, 2013e)

Priority	Description
1 The Reserve	Basic human needs at minimum 25 litres per person per day; the ecological requirement.
2 International obligation	International water requirements in terms of the agreements with riparian countries.

Priority	Description
3 Poverty eradication and equity	Water for poverty eradication, the improvement of livelihoods of the poor and the marginalised, and uses that will contribute to greater racial and gender equity.
4 Strategic importance	These are uses that are of critical importance to the nation and must be authorised by the Minister. The uses include: • The transfer of water from one WMA to another. • The continued availability of water to be used for electricity generation throughout the country.
5 General economic purposes	Includes commercial irrigation and forestry. In this category, allocation is best dictated by prevailing local and regional dynamics and requirements. Demand will reflect the value of water in particular economic sectors and will encourage uses that create employment, contribute to the economy (GGP) and are efficient.

4.2 Role Players

4.2.1 The DWS

The Minister of Water Affairs is responsible for managing and administering water resources as the public trustee, ensuring that the country's water resources are managed for the benefit of all, that water is allocated equitably, and that environmental values are promoted. According to Article 26 of the NWA, subject to Article 4: "the Minister may make regulations limiting or restricting the purpose, manner or extent of water use". General water management functions are delegated to the DWS. The DWS is responsible for implementing the two major legal instruments relating to water: the Water Services Act, no. 108 of 1997, and the NWA, no. 36 of 1998.

The DWS consists of a number of directorates, all performing different functions. The purpose of the Chief Directorate Integrated Water Resource Planning (IWRP) is to ensure availability of adequate water that is fit for use. This is done through holistic planning for the management and development of water resources and systems.

The IWRP function is under the DWS sub-programme of Integrated Planning, which develops comprehensive plans that guide all initiatives and infrastructure development within the water sector; taking water needs of all users into account and identifying the appropriate mix of interventions. This will ensure a reliable supply of water in the most efficient, sustainable and socially beneficial manner. The purpose is to ensure that the country's water resources are protected, used, developed, conserved, managed and controlled in a sustainable manner to benefit all people and the environment through effective policies, integrated planning, strategies, knowledge base and procedures.

Four chief directorates reside under IWRP:

- **National Water Resource Planning** develops national strategies and procedures for the reconciliation of water availability and requirements to meet national social and economic development objectives including strategic requirements, resource quality objectives and international obligations.
- **Options Analysis** identifies and evaluates water resource management options/projects to meet future water requirements and for multi-disciplinary project planning to implement these options, including the development of applicable procedures and guidelines.

- **Water Resource Planning Systems** evaluates strategic water resource management challenges, provides expert planning related support and develops planning and management decision support systems with regard to operating rules, water quality, integrated hydrology (including geohydrology) and socio-economic aspects of water resources.
- **Climate Change** contributes to water-related policies and develops appropriate adaptation strategies for the water sector in response to climate change.

4.2.2 Catchment management agencies

In South Africa, a vital component of Integrated Water Resources Management is the progressive devolution of responsibility and authority over water resources to CMAs. The initial scale of operation for the CMAs is that of WMAs (NWA, no. 36 of 1998). In terms of the NWRS, 19 WMAs are delineated in South Africa, with CMAs in various stages of establishment. More recently, a change in approach has seen some CMAs cover more than one WMA, with the intention that nine CMAs will be formed throughout the country.

Section 80 of the NWA describes the initial functions of a CMA:

- To investigate and advise interested persons on the protection, use, development, conservation, management and control of the water resources in its WMA.
- To develop a catchment management strategy.
- To coordinate the related activities of water users and of the water management institutions within its WMA.
- To promote the coordination of its implementation with the implementation of any applicable development plan established in terms of the Water Services Act, 1997 (Act No. 108 of 1997).
- To promote community participation in the protection, use, development, conservation, management and control of the water resources in its WMA.

4.2.3 Pricing strategy for water-use charges (November 2015)

The priority against which water is allocated is directly proportional to the assurance of supply. The higher the priority, the higher the assurance at which that water should be applied to the specific user category. Furthermore, monetary charges are also allocated to the various water user sectors and include the assurance of supply factor. The higher the assurance at which water is supplied to a specific water user, the higher the charge.

Strategic water users need a high assurance of supply with the probability of a system failure not more than once in 200 years. This assurance of supply equates to 99.5% with a probability of failure of 0.5%. Municipal, industrial/mining users have an assurance of supply of 97% while the assurance of supply requirement for the agricultural sector can be as little as 70%. This equates to an allowance of a risk of failure of once every four years. Agriculture uses large volumes of water and pay less per unit of water than the other economic water user sectors, due to lower assurance of supply.

For irrigation schemes, the allocation of water has been based on a quota system where a specific volume of water is allocated to a scheduled area. This quota represents the upper limit of the irrigation water requirement since the allocated quantity of water is the probable water requirement under dry conditions. It might happen that the total scheduled area is not used but the total allocated volume is, or that a larger area is irrigated with the same allocated volume (WRC, 2014).

4.3 Study Areas

4.3.1 Orange River System

4.3.1.1 Background

The Orange River System is the largest river basin in South Africa and in Africa south of the Zambezi. The Orange River originates from the tributaries of the Senqu River sub-basin in the highlands of Lesotho at elevations of 3000 m above sea level and more. From there it meanders through the mountainous eastern parts of the country crossing the border of the RSA from where the topography gradually flattens. In the RSA, the Orange River forms the southern and south-eastern border of the Free State Province where it is impounded by the two largest dams in the RSA, namely, Gariep and Vanderkloof. Downstream of Vanderkloof Dam, the elevation profile is fairly level as the river flows through the semi-arid Karoo and Kalahari plains of the Northern Cape Province. It meets with the Vaal River at the town Douglas and eventually, after rapidly descending at the Augrabies waterfall, serves as international boundary between the south of Namibia and the RSA. Eventually after 2300 km, the Orange River flows into the Atlantic Ocean at Alexander Bay, which is situated on the western coast of the RSA. The main stem of the Orange River from Gariep Dam to approximately 200 km upstream of the estuary forms part of the Nama Karoo ecoregion comprising a number of different vegetation types, and which mainly receives summer rainfall. The last stretch of the river flows in the Succulent Karoo, a region which experiences inconsistent and highly variable rainfall throughout the year (ORASECOM).

The average rainfall in the Orange River basin is 300 mm/annum ranging from more than 2000 mm/annum in Lesotho in the east to as little as 30 mm/annum in some areas in the western part of the basin known as the Lower Orange. Here, evaporation can reach extremes of 3000 mm/annum resulting in an average per capita availability of water of just more than 1000 m^3/annum, which is the border line between a chronic stressed (500 m^3/annum to 1000 m^3/annum) and a water-stressed (1000 m^3/annum to 1700 m^3/annum) region. For the purpose of this study, when referring to the Orange River System, it includes the regions supplied with water from the Gariep and Vanderkloof dams. These regions include parts of the Eastern Cape and exclude the regions upstream of the Gariep Dam.

The Gariep Dam is the largest storage dam in South Africa with a storage capacity of 5200 million m^3. The Vanderkloof Dam is the second-largest dam in South Africa with a storage capacity of 3170 million m^3. These two dams are known as the Orange River Project, which was initiated to:

- Make provision for new irrigation development along the Orange River and various other areas within reach of the river.
- Stabilise the water supply to existing irrigation schemes.
- Afford new life to the fertile but water-deficient Great Fish River and Sundays River valleys.
- Supply water to various urban centres.
- Generate hydro-electric power.

The Vanderkloof Dam forms an integral part of the Orange River Project and was commissioned in 1971. It is also used for hydropower generation. It supplies water to the Riet River catchment and downstream users, which include the Vanderkloof WUA, Orange–Vaal WUA, Boegoeberg WUA, Kakamas WUA, mine companies, small towns and some bigger towns such as Upington.

The Orange–Fish water transfer scheme is another component that forms an important part of the Orange River Project. This scheme comprises a 5.35 m diameter tunnel over 82.8 km, which was constructed to convey water from the Gariep Dam to the Great Fish and Sundays rivers in the Eastern Cape (DWS). Figure 24 shows the part of the Orange River System relevant to this study encircled in black.

Figure 24: The Orange River System from Gariep Dam and downstream (DWS, 2015)

4.3.1.2 Urban water requirements

Table 19 lists the urban water requirements in the Orange River (Orange River Project) System per river reach and economic region at the 2016 development level as configured in the WRPM. This data was sourced from the updated water requirements for the Orange AOA 2016/2017.

Table 19: Orange River urban water requirements 2016

User	WRPM channel	Volume (million m³)	Reach	Economic region
Orange–Fish Urban	529	52.73	–	EC[a]
Gariep Urban	1 883	3.5	6	UOW[b]
Hopetown	1 745	2.4	9	UOW
Douglas	497	2.48	14	UOW
Richie	1 843	2.56	7	UOW
Prieska	1 842	1.78	15	LOE[c]
Upington Urban	1 893	16.8	16	LOW[d]
Kakamas Urban	1 884	6.1	17	LOW
Namakwa Urban	1900	16	20	LOW
Springbok	1 818	11.5	20	LOW
Alexander Bay Urban	1924	6.74	22	LOW
Rosh Pina Urban	1 865	8.4	22	LOW
Rosh Pina Mine	1 817	7.86	22	LOW
Haib Urban	1906	6	21	LOW
Venterstad	4 324	0.44	6	UOW
Ariamsvlei	3 129	0.23	20	LOW

User	WRPM channel	Volume (million m³)	Reach	Economic region
Aussenkehr	3 130	0.4	21	LOW
Total		**145.92**		

[a] Eastern Cape, [b] Upper Orange West, [c] Lower Orange East, [d] Lower Orange West

4.3.1.3 Irrigation water requirements

Table 20 lists all the irrigation water volume and area estimates for each of the 22 river reaches in the Upper and Lower Orange CMAs) and cross-border components. Table 21 lists all the irrigation channels configured in the WRPM subject to restrictions, categorised per river reach for comparison purposes. The bulk of the water requirement information was sourced from the Orange Recon Irrigation Demands and WC/WDM report (Task 8) and the most recent updates from the Orange AOA (2016/2017).

Table 20: Irrigation along the Orange River reaches (DWA, 2014)

River reach	Description	Irrigation demands (million m^3/a)	Irrigation areas (ha)
1	Caledon River: Upstream (u/s) Welbedacht Dam	40.3	9 930
2	Caledon River: Welbedacht Dam to Gariep Dam	36.5	5 835
3	U/s Aliwal North Downstream (d/s) Oranjedraai	6.6	877
4	Aliwal North to Gariep Dam	52.5	8 229
5	U/s Aliwal North	28.0	6 341
6	Gariep Dam to Vanderkloof Dam	27.7	3 121
7	Canals ex Vanderkloof Dam	195.1	17 678
8	Schotzburg and Lower Riet Irrigation Boards	50.2	4 564
9	Vanderkloof–Marksdrift	187.4	17 455
10	Krugersdrift Dam to Tweerivier Gauge – Modder River	52.5	7 004
11	Tierpoort Dam to Kalkfontein Dam: Tierpoort Irrigation Board	8.1	1 018
12	Kalkfontein Dam to Riet River Settlement: Kalkfontein (WHA Canal)	56.7	6 187
14	Douglas Weir to Orange–Vaal Conf. (Orange Water)	104.3	11 410
15	Orange–Vaal Confluence to Boegoeberg Dam	174.0	17 236
16	Boegoeberg dam to Gifkloof Weir	161.2	10 744
17	Gifkloof Weir to Neusberg	222.8	14 855
18	Neusberg to Namibian Border	180.2	12 016
19	Namibia Border to Onseepkans Weir	28.6	1 905
20	Onseepkans Weir to Vioolsdrift Weir	33.6	2 237
21	Vioolsdrift to Orange–Fish Confluence	9.0	600.0
22	Orange–Fish Confluence to River Mouth	8.3	553
Sub-total	**Upper Orange (Reaches 1–14)**	**846**	**99 647**
Sub-total	**Lower Orange (Reaches 15–22)**	**818**	**63 109**
	Molopo	1.9	127
	Lower Orange Tributaries	19.8	1 320
Total	**Orange River**	**1 685**	**164 203**

River reach	Description	Irrigation demands (million m^3/a)	Irrigation areas (ha)
	Eastern Cape	577.2	49 565
Total	**RSA Demand**	**2 262**	**213 768**
	Lesotho	20.6	2 640
	Namibia Fish River	47.5	2 520
	Namibia Main Orange	35.2	2 961
Total demand		**2 366**	**221 889**

Table 21: Irrigation channels in WRPM categorised per river reach

Channel number	Up-stream node	Down-stream node	Irrigation block	Area (km^2)	Volume (million m^3)	User	Reach	Economic region
530	1 063	1998	n		578.48	Eastern Cape (EC)	–	EC[a]
1 878	1 770	1998	239	123.35	171.33	Orange–Riet	7	UOW[b]
484	707	1998	n	24.72	21.94	Gariep Comp	6	UOW
2 171	1 824	0	n		24.73	RPF	9	UOW
1 853	1 795	1998	n	49.46	53.34	Ramah	7	UOW
543	146	1998	n	42.87	46.24	Torquy to Vaal	9	UOW
525	187	99	5	73.90	94.18	Douglas Weir	14	UOW
1 846	1 801	99	1 803	172.36	173.57	Diffuse Mid Orange	15	LOE[c]
1 854	1 805	99	1 807	76.79	131	Boegoe	16	LOW[e]
1 855	1 817	99	700	60.14	90.02	UPN	16	LOW
1 866	1 817	99	1 811	78.96	134.48	UPN	17	LOW
1 897	1 818	99	1 815	40.10	68	Keimoes	17	LOW
1927	1 819	99	1 821	87.35	138.21	Neusberg	18	LOW
1 857	1 819	99	701	24.26	36.88	Neusberg	18	LOW
1 894	1 823	99	708	26.93	14.73	Namibia	19	LOW
1 898	1 825	99	709	29.94	68	Namakwa	20	LOW
1 859	1 825	99	710	15.23	9.9	Namibia	20	LOW
2 147	1 827	99	691	6.00	9.8	Viool	21	LOW
2 146	1 827	99	692	20.23	37.11	LO	21	LOW
3 139	1 825	99	n		18	LO RPF	21	LOW
1918	1 831	99	711	5.53	8.3	Alex Bay	22	LOW
490	481	99	482	38.53	65.54	Orange–Riet	8	UOW
483	477	99	479	3.00	2.66	Scholtz	8	UOW
1973	593	99	594	7.00	9.02	Orange–Riet	8	UOW
1 743	1 746	1998	n	130.85	141.13	Vdk to Torq	9	UOW
450	169	1999	n	20.67	26.34	Douglas	14	UOW
				1 158.2	2 172.9[d]			
Total					**2 093.1**			

[a] Eastern Cape, [b] Upper Orange West, [c] Lower Orange East, [d] Includes resource-poor farmers (RPFs), [e] Lower Orange West

For the previous studies pertaining to the Orange River System, an approach was followed whereby the Orange River and its major tributaries were divided into 22 river reaches. The Orange River, being one of the selected areas for this research, includes only the users requiring water from the Gariep and Vanderkloof dams. Therefore, irrigation demands and areas only from Reaches 6–9 and Reaches 14–22 were reviewed for this study. Due to the availability of various sources of irrigation data, some comparisons had to be made to ensure similar data will be used as input to both the WRPM and WIM.

The Upper Orange West consists of the region between the Gariep Dam and the confluence of the Orange River and the Vaal River. Table 22 compares the irrigation data obtained from the Orange Recon and that of the most recent configured in the WRPM for the Upper Orange (West) region.

Table 22: Comparison of irrigation data in the Upper Orange (West) river reaches

Reach	Description	Irrigation demands (million m³/a)		Volume difference	Irrigation areas (ha)		Area difference
		Orange Recon	*WRPM*		*Orange Recon*	*WRPM*	
6	Gariep Dam to Vanderkloof Dam	28	*22*	(6)	*3 121*	2 472	(649)
7	Canals ex Vanderkloof Dam	195	*225*	30	*17 678*	17 281	(397)
8	Scholtzburg and Lower Riet Irrigation Boards	50	*77*	27	*4 564*	4 853	289
9	Vanderkloof to Marksdrift	187	*187*	0	*17 455*	17 373	(82)
14	Douglas Weir to O/V Confluence (Orange Water)	104	*121*	16	*11 410*	9 456	(1 954)
Total		**565**	**632**	**71**	**54 228**	**51 435**	(2 793)

The volume of 632 million m³/a from the Orange AOA 2016/2017 WRPM data and the irrigation area of 54 228 hectares from the Orange Recon were accepted for the economic analyses to be carried out in this research study.

The water transferred from the Gariep Dam to the Eastern Cape is also from the Orange River System; therefore, the irrigation areas and volumes for the crops cultivated in the Great Fish WUA and Sundays River WUA should also be included in the analyses. A total volume of 578 million m³/a is transferred for irrigation on a rateable area of 49 875 hectares.

Table 23 compares the irrigation data obtained from the Orange Recon and that of the most recent configured in the WRPM for the Lower Orange region. The big differences in river Reaches 20 and 21 may be attributed to the fact that the irrigation data indicated here does not take the water requirements along the Orange River of the Namibian users into account. These areas and demands are listed in Table 24. There are also large discrepancies specifically in terms of the areas in reaches 16 to 19.

Table 23: Comparison of irrigation data in the Lower Orange River reaches

Reach	Description	Irrigation demands (million m³/a)		Volume difference	Irrigation areas (ha)		Area difference
		Orange Recon	*WRPM*		*Orange Recon*	*WRPM*	
15	Orange–Vaal Confluence to Boegoeberg Dam (East)	174	*174*	0	*17 236*	17 236	–
16	Boegoeberg Dam to Gifkloof Weir	161	*221*	60	*10 744*	13 693	2 949
17	Gifkloof Weir to Neusberg	223	*202*	(20)	*14 855*	11 906	(2 949)

Reach	Description	Irrigation demands (million m³/a)		Volume difference	Irrigation areas (ha)		Area difference
18	Neusberg to Namibian Border	180	*175*	(5)	*12 016*	11 161	(855)
19	Namibia Border to Onseepkans Weir	29	*15*	(14)	*1 905*	2 693	788
20	Onseepkans Weir to Vioolsdrift Weir	34	*78*	44	*2 237*	4 517	2 280
21	Vioolsdrift to Orange–Fish Confluence	9	*10*	1	*600*	2 623	2 023
22	Orange–Fish Confluence to River Mouth	8	*8*	0	*553*	553	-
Total		**818**	**883**	**65**	**60 146***	**64 382**	4 236

*17 236 in the Orange River (East) reach 15, *42 910 for the Orange River (West) Reach 16 to 22

More recent studies[2] additional to that of the Orange Senqu Commission (ORASECOM) and Orange Recon indicated an irrigation area of 43 339 ha for the Lower Orange West region. This area, which has recently been configured and used in the WIM, is in line with the area indicated for the Lower Orange (West) in Table 6-4, p. 34 of the *Irrigation Demands and WCWDM Report* (Task 8) of the Orange Recon Study (DWS, 2013c). In terms of the irrigation volumes, the most recent data available is that from the Orange AOA 2016/2017 with a total volume of 883 million m³/a, which is also configured in the data set to be used for the research analyses. It was therefore decided that the irrigation area of 60 146 hectares in combination with the volume of 883 million m³/a, which excludes the future allocation of the RPF, will be used for this study.

Some of the most common crops cultivated along the Orange River reaches are listed in Table 24. These crops include those cultivated in the Great Fish and Sundays River catchments in the Eastern Cape as well, which depend on the Orange–Fish Transfer Scheme from Gariep Dam for water.

Table 24: Irrigation along the Orange River reaches (DWAF, 1997)

Crops	Area (hectares)	Average water use (m^3/ha)	Volume (million m^3)
Maize	29 956	10 947	328
Soya beans	2 659	12 609	34
Dry Beans	3 141	8 264	26
Industrial tomatoes	–	–	–
Fresh tomatoes	–	–	–
Potatoes	5 097	10 849	55
Summer vegetables	1 670	7 635	13
Winter vegetables	2 790	6 476	18
Wheat	31 209	9 295	290
Lucerne	42 567	14 768	629
Sugar cane	–	–	–
Bananas	–	–	–
Grapes – fresh	6 901	16 886	117
Grapes – wine	5 922	18 000	107

2 Economic Cost Benefit Analysis and Land Trade-off Assessment of the Bokpoort Project 150 MW CSP Tower Development. Determination of Ecological Water Requirements for Surface Water (River, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA – Report on Consequences of Scenarios. Report Number: RDM/WMA06/00/CON/COMP/0117.

Crops	Area (hectares)	Average water use (m^3/ha)	Volume (million m^3)
Grapes – dry	18 837	18 000	339
Macadamias	–	–	–
Citrus – oranges	13 244	9 369	124
Citrus – grapefruit	–	–	–
Avocados	–	–	–
Litchis	–	–	–
Deciduous fruit	–	–	–
Palm dates	687	21 000	14
Mangoes	–	–	–
Total	**164 678**		**2 093***

*Excludes RPFs

A detailed study of the crops irrigated in the Orange River System was last done for the Orange River Replanning Study (ORRS) in 1997 (DWAF, 1997). The same cropping pattern based on that sourced from Table 6-4 in the Orange Recon Task 8 report (DWS, 2013c) is applied to the irrigation areas adopted for this research study. The cropping pattern adopted for the Eastern Cape for the water transferred from Gariep Dam for irrigation use was sourced from the Great Fish River and Sundays River WUAs.

Table 25 summarises the cropping pattern per selected economic region in hectares. Table 26 summarises the cropping type distribution in the Orange River System. According to the crop type classification in Appendix 3 – Classification of Crops (a report by the Food and Agricultural Organisation of the United Nations as part of the World Programme for the Census of Agriculture) (FOA, 2010) and the cropping pattern identified in the Orange River System, 75% of crops cultivated are considered permanent and 25% are temporary. This is important to consider when defining the user priority classification criteria as permanent crops require a higher assurance of water supply than temporary crops to maintain viable farming practices.

Table 25: Cropping pattern per economic region in the Orange River System (hectares)

Crop	UOW	%	LOE	%	LOW	%	EC	%
Maize	18 320	34%	4 104	24%	2 789	6%	3 990	8%
Dry beans	2 443	5%	2 627	15%	858	2%	–	
Pastures	4 885	9%	985	6%	3 776	9%	33 417	67%
Winter vegetables	977	2%	656	4%	–	0%	–	
Potatoes	2 931	5%	656	4%	–	0%	–	
Wheat	24 427	45%	8 208	48%	4 291	10%	–	
Citrus	–	0%	–	0%	815	2%	12 469	25%
Table grapes (vine)	244	0%	–	0%	5 364	12%	–	
Wine grapes (white)	–	0%	–	0%	5 922	14%	–	
Dry fruit (vine)	–	0%	–	0%	18 837	43%	–	
Dates	–		–		687	2%	–	
Total	**54 228**	**100%**	**17 236**	**100%**	**43 339**	**100%**	**49 875**	**100%**

UOW – Upper Orange West; LOE – Lower Orange East; EC – Eastern Cape

Table 26 shows the percentage distribution per crop type in the Orange River System.

Table 26: Crop type distribution percentage – Orange River

Crop	Percentage (%)	Type	Percentage (%)
Maize	18%	Temporary	75%
Dry beans	5%		
Pastures	23%		
Winter vegetables	1%		
Potatoes	2%		
Wheat	26%		
Citrus	7%	Permanent	25%
Table grapes (vine)	3%		
Wine grapes (white)	3%		
Dry fruit (vine)	11%		
Dates	0%		

4.3.1.4 Scenario development

Various yield analyses were carried out for planning purposes taking possible intervention options and the timing of implementation into consideration in order to continuously reconcile the water availability in the resource system with the increasing demand. Results of the WRYMs that were created from different scenarios analysed are presented in Table 27.

When new intervention options are considered to balance the available supply with the growing demand of a water resource system, it requires a significant number of yield analyses to develop new sets of short-term curves. For the Orange Recon, however, additional yield analyses could not be executed at the time and the two following approaches were used: One approach included using all the required sets of short-term stochastic yields for the Integrated Vaal River System (IVRS), Orange River System and Greater Bloemfontein system while the second approach excluded the short-term stochastic yields for the Orange River and Greater Bloemfontein systems. For the first approach, in order to prevent the resources form completely failing, restrictions need to be imposed on the main systems during drought events.

When considering different user priority criteria, the assurance of supply can be evaluated by means of a curtailment plot that represents the results from the WRPM analysis output. If, by interpretation of this plot, curtailments need to be imposed on the system regularly, it may indicate that the system is not able to adhere to the assurance of supply requirements anymore and intervention will be needed at that time.

For the second approach, no restrictions were imposed on the Orange River and Greater Bloemfontein systems and it would be of no use to evaluate the assurance of supply to the systems. The method to follow is to evaluate the projected storages of the dams supporting the particular system and to identify at what time and risk will the system reach its minimum operating level, thus the storage of the system be depleted.

Table 27: Results of WRYM analyses (values given in million m^3/a) (DWS, 2015)

Scenario	Brief description	Surplus /deficit	With EWR	No EWR	Yield increase	Live storage increase	Total evapo-ration	Evapo-ration increase	Spills	Spills difference
1	Current day	212	3 038	3 325			815		4 062	0
2b	Current day + new environmental water requirement (EWR) no high flows	−213	2 613	3 325	−425	0	825	10	4 421	358
4d	Polihali full transfer to Vaal new EWR & Vioolsdrift reregulating dam & new EWR	−753	2 299	3 021	120	110	834	19	4 093	31
5di	Polihali full Vaal transfer, Vioolsdrift yield (510) & reregulating dam current EWR	−561	2 491	3 213	192	250	836	0	4 055	0
6b	Polihali, full Vaal transfer, Raised Gariep by 10 m & Viools yield (510) & reregulating	−211	2 841	3 563	350	4 735	1 119	283	3 503	−552
7d	Polihali, full Vaal transfer, Bosberg (3 065) & Viools Yield (510) & reregulating	−184	2 868	3 590	377	3 315	890	54	3 683	−372
8d	Polihali, full Vaal transfer, Boskraai (8 288) & Viools Yield(510) & reregulating	376	3 428	4 150	937	8 538	978	142	3 134	−921
9c	Polihali, full Vaal transfer, Ntoahae (1 720, 20 dead) & Viools yield (510) & reregulating	−329	2 723	3 445	232	1 950	839	3	3 841	−214
10c	Polihali, full Vaal transfer, Malatsi (878, 7.5 dead) & Viools yield (510) & reregulating	−442	2 610	3 332	119	1 121	842	6	3 943	−112
11	Polihali, full Vaal transfer, VDK low-level use & Viools yield (510) & reregulating	−424	2 628	3 350	137	1 100	815	−21	3 939	−116
12a	Polihali, full Vaal transfer, Kraai (929) & Viools yield (510) & reregulating	−477	2 575	3 297	84	1 179	909	73	3 938	−117
12b	Polihali, full Vaal transfer, Kraai (2 971) & Viools yield (510) & reregulating	−231	2 821	3 543	330	3 221	955	119	3 688	−366
13a	Polihali, full Vaal transfer, Raised Gariep by 10 m, VDK low-level use & Viools reregulating corrected *	−234	2 818	3 540	327	5 450	1 073	237	3 587	−468
13b	Polihali, full Vaal transfer, Raised Gariep by 10 m, VDK low-level use & Viools yield (510) & reregulating *	−72	2 980	3 702	489	5 590	1 067	232	3 403	−652
13c	Polihali, full Vaal transfer, Raised Gariep by 10 m, VDK low-level use & Viools yield (544.8) & reregulating	−67	2 984	3 706	494	5 625	1 077	241	3 400	−655
14	Polihali, full Vaal transfer, Verbeeldelingskraal (1 363) & Viools Yield (510) & reregulating	−409	2 642	3 364	152	1 613	895	59	3 883	−172
15	Polihali, full Vaal transfer, Raised Gariep by 10 m, VDK low-level use & Viools yield (510) & reregulating *	85	3 136	3.858	646	6 953	1 100	264	3 256	−799

Note: *–Gain in yield due to Vioolsdrift yield dam is 162 million m^3/a thus 30 million m^3/a less than 5di

Scenario 1 in the Orange Recon Study was set up to determine the timing of intervention options after the future implementation of Polihali Dam, Phase 2 of the Lesotho Highlands Water Project (LHWP). Flows entering the Gariep and Vanderkloof dams will be impounded by the Polihali Dam, which will result in a reduction in the yield of the Orange River System due to reduced inflows and, subsequently, a deficit in the Orange River System. This scenario includes WC/WDM, real-time modelling and monitoring to reduce operating requirements and shared utilisation of the Polihali Dam from 2022. Sub-scenarios considered for the WRPM analyses included:

- Scenario 1a: Includes restriction rules.
- Scenario 1b: Excludes restriction rules.
- Scenario 1c: Scenario 1a using alternative assurance of supply criteria.

Run control settings in the WRPM are used to define general information on how the system will be analysed for a particular model run. For the planning analysis this includes, most importantly, the following:

- 501 sequences were analysed.
- A 27-year projection run was carried out, which started in May 2014.
- The major dams were set to start the analysis at their actual observed levels on 1 May 2014.
- Demands were set to grow according to their projections till the year 2040.

The priority classifications presented in Table 28 were used for the different water users.

Table 28: Assurance of supply criteria Orange River System

Water supply sector	Percentage of water demand to be supplied at given assurance			
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Medium (98% assurance) 1 in 50 year	Low (95% assurance) 1 in 20 year
Irrigation	10	40	0	50
Urban	50	30	0	20
Losses	100	0	0	0

Results

Scenario 1a

The curtailment plot in Figure 25 is a result of the WRPM analysis for Scenario 1a and indicates a continuous violation of the curtailment criteria of the Orange River System from 2019 onwards (areas in red). The increase in the initial small violation is a result of the water being impounded by Polihali Dam from 2022 onwards.

Scenario 1b

Scenario 1b was based on the second approach (the risk of non-supply) and excluded the use of the short-term stochastic yield curves for the Orange River. The combined Gariep and Vanderkloof Dam storage projection plot (Figure 26) indicated a possible failure in supply at the 99.5% risk level (1 in 200-year recurrence interval) by 2020 and for the 99% risk level (1 in 100-year recurrence interval) by 2022. This result is in line with the results obtained from Scenario 1a, although approximately one to two years earlier, depending on the significance of the shortages experienced.

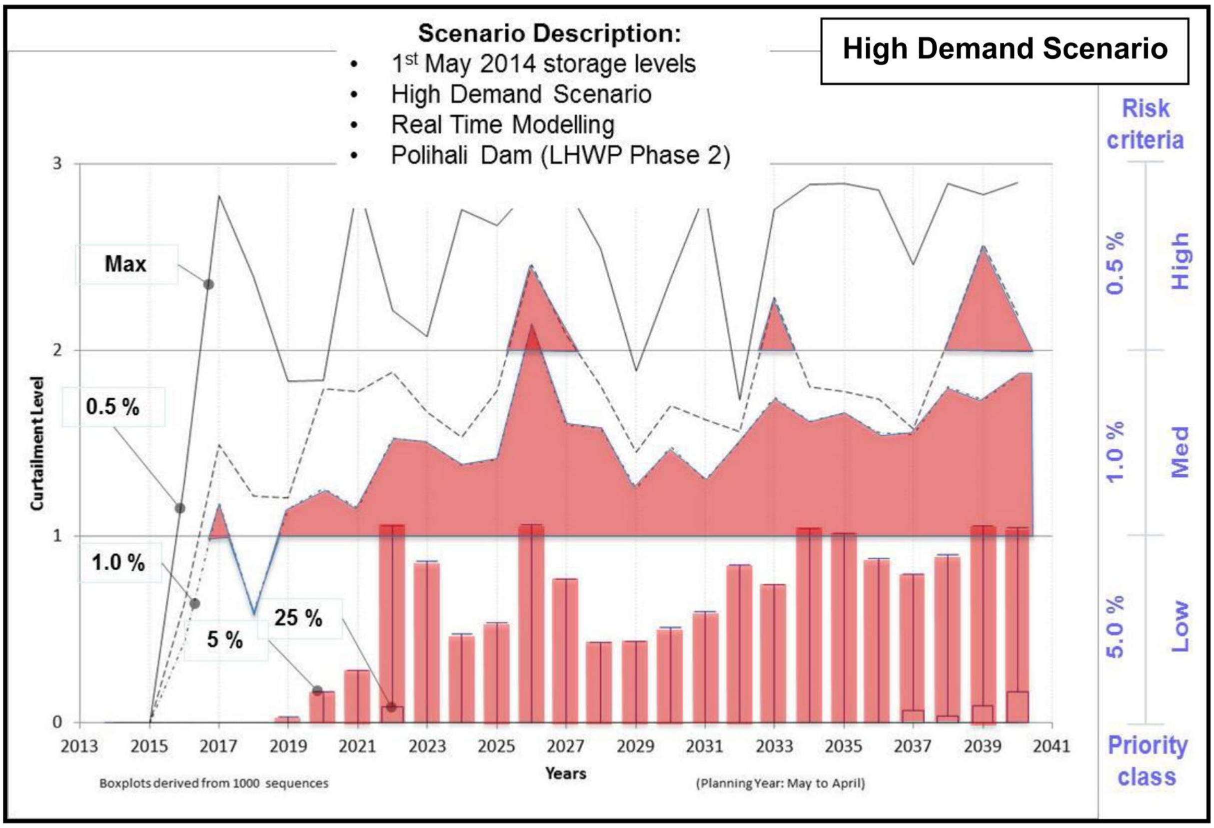


Figure 25: Scenario 1a Orange River System curtailment plot (DWS, 2015)

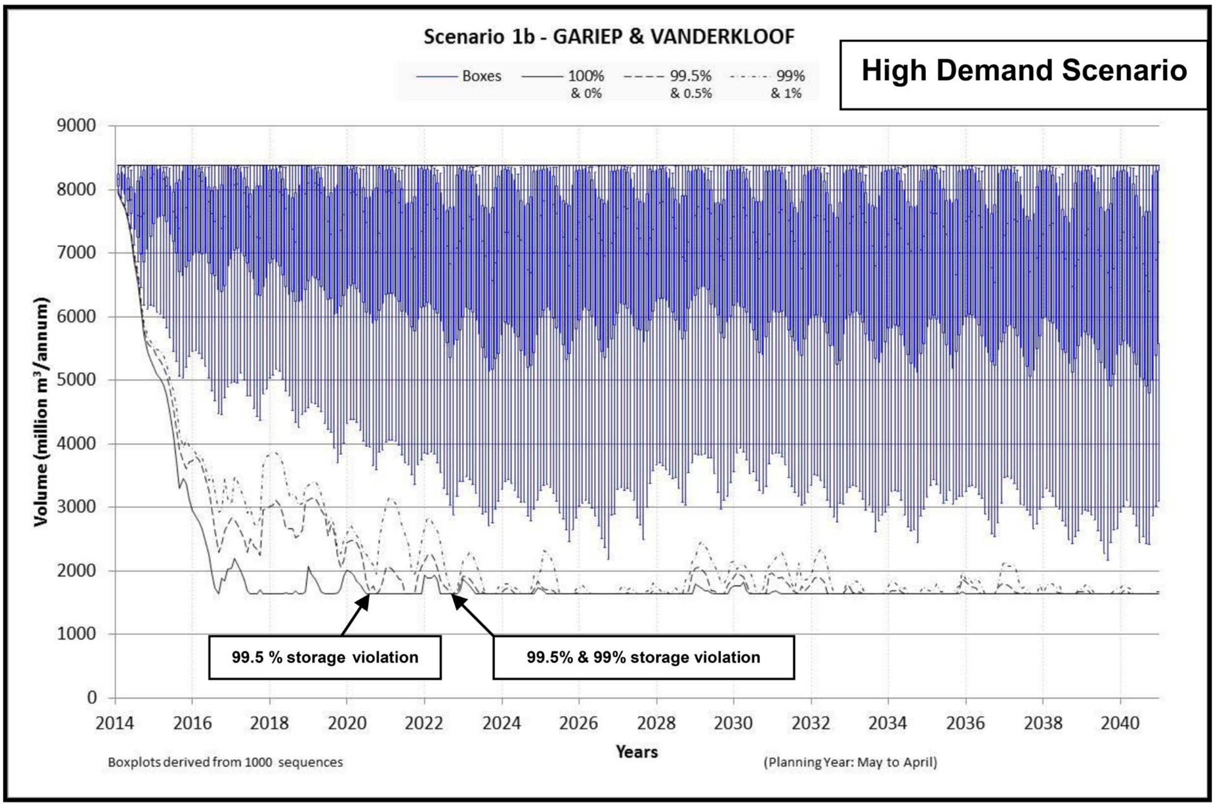


Figure 26: Scenario 1b Orange River System storage projection plot (DWS, 2015)

Scenario 1c

Alternative assurance of supply criteria were used for Scenario 1c. This scenario required the short-term stochastic yield characteristics as part of the operating rule to be used to determine the impact of the reduced assurance of supply to the users from the Orange River System. The reduced assurance of supply used for this scenario is shown in Table 32, with the current assurance of supply allocations indicated by the values given in brackets. The user priority for this scenario defines that 70% of irrigation is supplied at a 1 in 10-year assurance and 30% in 1 in 100-year assurance.

Results from this analysis show a significant reduction in the violation of the curtailment criteria, which are only pertinent from the inclusion of Polihali Dam in 2022 onwards. This scenario would increase the available yield at the 1 in 10-year level of assurance of supply by 170 million m³/annum.

Another scenario in terms of the assurance of supply criteria was evaluated in addition to Scenario 1c, which was named Scenario 2. The detail is given in Table 33. This scenario would increase the available yield at the 1 in 10-year level of assurance of supply by 250 million m³/annum.

Table 29: Assurance of supply criteria Scenario 1c (Scenario 3)

Water supply sector	Percentage of water demand to be supplied at given assurance			
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Medium (95% assurance) 1 in 20 year	Low (90% assurance) 1 in 10 years
Irrigation	0 (10)	30 (40)	(50)	70
Urban/mining	50	30	(20)	20
Losses	100			
Environmental	68	0	32	0

Table 30: Assurance of supply criteria Scenario 2

Water supply sector	Percentage of water demand to be supplied at given assurance		
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Low (90% assurance) 1 in 10 years
Irrigation	0	0	100
Urban/mining	50	30	20
Losses	100	0	0
Environmental	68	0	32

These two scenarios were presented and discussed at the Third Study Steering Committee Meeting for the Development of Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River in November 2013 (DWA, 2013a). The interpretation of the results conceded that a lower assurance of supply leads to a larger volume of water that can be supplied but offers less protection of the system or source during extreme dry periods. The water supply to the urban/industrial sector will also improve as a result of lower assurance of supply to the irrigation sector. The impact on the urban sector will be more severe in extreme droughts than for irrigation.

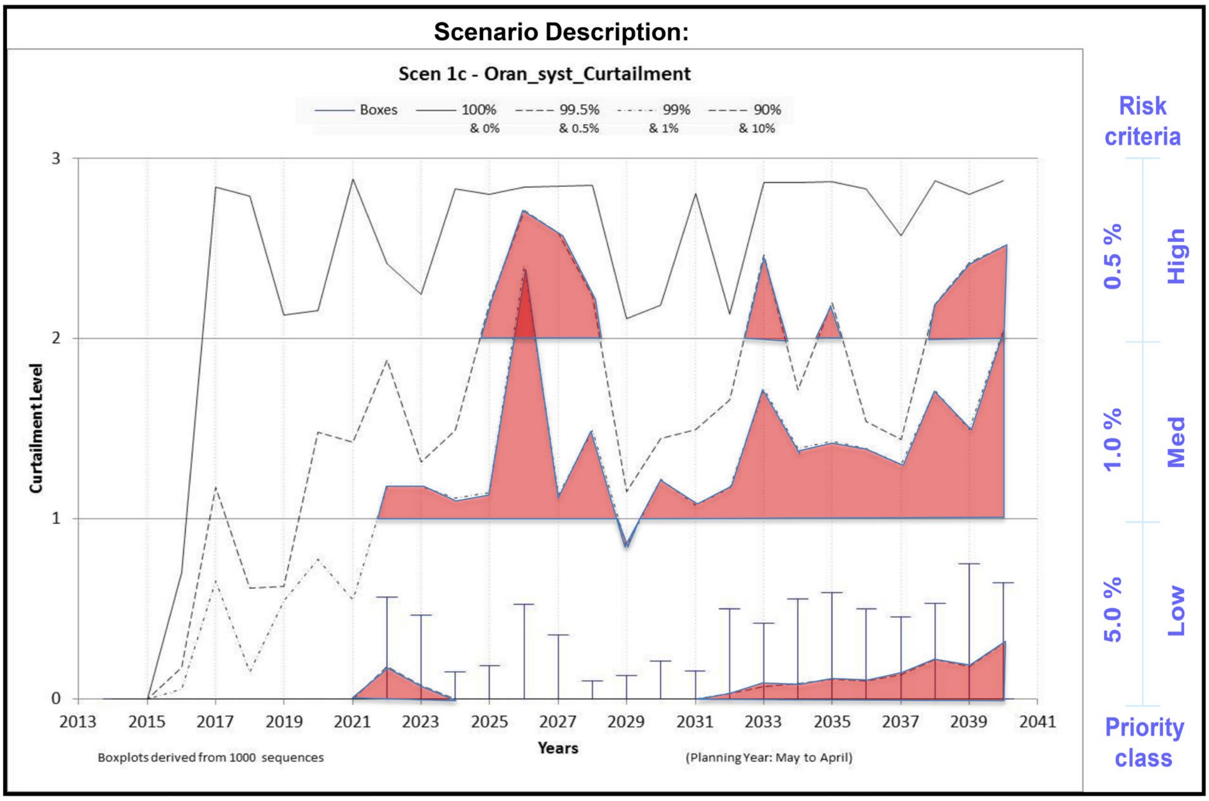


Figure 27: Scenario 1c Orange River System curtailment plot (DWS, 2015)

Table 31 to Table 33 present the volumetric distribution of the water requirements of the different user sectors at the different level of assurance of supply in million m³/annum. The total requirement is used at the 2016 development level, which was updated for the Orange River AOA 2016/2017.

The demands on the Orange River System for the different assurance of supply criteria were each plotted firstly on the long-term stochastic curve (Figure 28) generated for the Orange River and then on the short-term yield reliability curves at different starting storages as illustrated in Figure 29 and Figure 30. These short-term firm yield reliability curves have been generated stochastically for a five-year period based on the operating rule of the Orange River System with and without Polihali Dam completed.

When looking at the demands prioritised at the different levels of assurance of supply, ideally one would want to postpone the implementation of restrictions but at the same time not have the system failing completely; i.e. reaching its minimum operating level below which no water can be used. Therefore, the firm yield lines of the short-term yield reliability curves at various system starting storage are a good first-order indication of the system's behaviour at the various prioritisations of the demands thereon. However, it is important to look at the base yield lines of a specific starting storage scenario to better establish the reliability of the system to supply the demands and the need for restrictions to prevent the system from failing.

Table 31: Volume for assurance of supply criteria Scenario 1

Water supply sector	Volume of water demand to be supplied at given assurance in million m³				
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Medium (95% assurance) 1 in 20 year	Low (90% assurance) 1 in 10 years	Total
Irrigation	217.29	869.17	1 086.46	0	**2 172.92**
Urban/mining	72.96	43.78	29.18	0	**145.92**
Losses	819.15	0.00	0.00	0	**819.15**
Environmental	195.50	0.00	92.00	0	**287.50**
Total	**1 304.90**	**912.94**	**1 207.64**	**0**	**3 425.49**

Table 32: Volume for assurance of supply criteria Scenario 1c (Scenario 3)

Water supply sector	Volume of water demand to be supplied at given assurance in million m³				
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Medium (95% assurance) 1 in 20 year	Low (90% assurance) 1 in 10 years	Total
Irrigation	0	651.88	0	1 521.04	**2 172.92**
Urban/mining	72.96	43.78	0	29.18	**145.92**
Losses	819.15	0.00	0	0.00	**819.15**
Environmental	195.50	0.00	0	92.00	**287.50**
Total	**1 087.61**	**695.65**	**0**	**1 642.23**	**3 425.49**

Table 33: Volume for assurance of supply criteria Scenario 2

Water supply sector	Volume of water demand to be supplied at given assurance in million m³				
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Medium (95% assurance) 1 in 20 year	Low (90% assurance) 1 in 10 years	Total
Irrigation	0	0	0	2 172.92	**2 172.92**
Urban/mining	72.96	43.78	0	29.18	**145.92**
Losses	819.15	0	0	0	**819.15**
Environmental	195.50	0	0	92.00	**287.50**
Total	**1 087.61**	**43.78**	**0**	**2 294.10**	**3 425.49**

For all scenarios plotted in Figure 29 and Figure 30, restrictions are only required when the system storage is at 40% or less; therefore, the short-term yield reliability curves for the 40% starting storage was reviewed in more detail as indicated in Figure 31 and Figure 32. These figures show that:

- For Scenario 1, the risk criteria is violated both when the Orange River System includes Polihali Dam and when it does not.
- For Scenario 2, the risk criteria is only violated when Polihali Dam is included and the system is at 40% and the demand of 3426 million m³/annum (2016) needs to be supplied.
- For Scenario 3, the system might be able to supply the 2016 demand when Polihali Dam is excluded; however, violation of the risk criteria is prone to occur at a risk of failure of 1 in 100 years and the allocation will need to be reviewed.

It is also important to note that although hydropower generation is not the primary purpose of the Orange River System, power cannot be generated at a combined Gariep and Vanderkloof storage capacity of below 3355 million m³, which relates to 40% of the full supply storage capacity. This once more emphasises the importance of engaging with stakeholders from all user sectors to find the best user priority definitions for the assurance of supply requirements.

The operating rules used in the analysis for the Orange Recon were aligned with the operating rule as applicable to the system setups used for the AOAs carried out for the IVRS, the Orange River and the Greater Bloemfontein System each year (DWS, 2015).

The AOA is important for the short-term planning and operations of the Orange River Water Supply System and is mainly driven by the starting storages of the major dams at the beginning of a dry season (May 2016) and the short-term demand projections of all the major water users in the system. Once more, this exercise entails a balance check between the available water in the system and the demand thereon for which the most recent updates were done in 2016.

The WRPM configuration as well as the user priority classification as applied in the Orange AOA 2016/ 2017 planning year will be adopted for analyses to be carried out in this research study as well.

Various scenarios were identified and analysed for the Orange AOA 2016/2017 to formulate with what seemed to be the best operating procedure in the short term. These scenarios are listed in Table 34. Some of the scenarios were based on the operational issues experienced during the 2015/2016 operating year, which included the following:

- The Eskom emergency power releases exceeded the normal allowable Eskom releases by 272 million m^3. Any further emergency releases by Eskom during the 2015/2016 year ceased when the Orange River System was declared as a drought area based on the results from the November 2015 operating analysis.
- Since the emergency releases by Eskom was put to an end, overruns from the normal allowed Eskom releases occurred several times, resulting in a total volume of 60 million m^3 released in excess of the agreed volumes.
- Releases through the Orange–Fish tunnel exceeded the allocated volume based on the irrigation quota times the scheduled area plus urban requirements by 126 million m^3.
- Releases above the given allocation were also evident from the Vanderkloof Canal releases with a 49 million m^3 exceedance by the Orange–Riet canal system and a 15 million m^3 exceedance through the Ramah Canal.

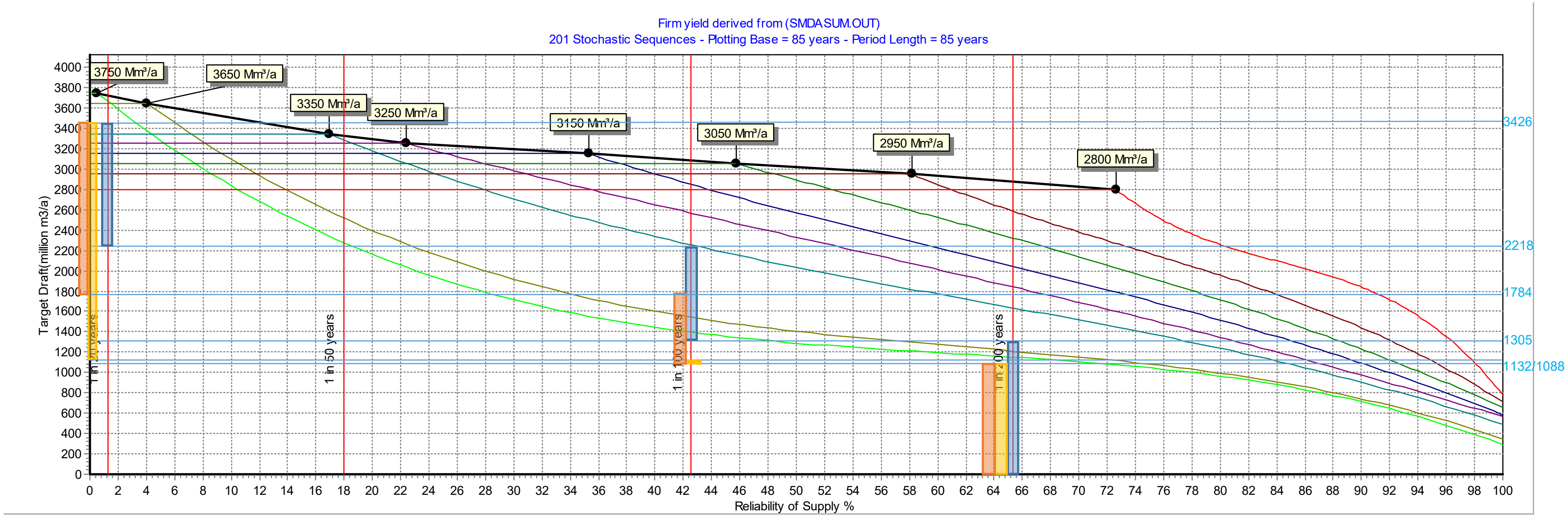


Figure 28: Long-term stochastic yield curve for the Orange River System

	Scenario 1	For the user priority defined in Scenario 1, with a total demand of 3426 million m³ imposed on the Orange River System, there is a deficit at the 1 in 50-year risk of failure level between the base yield and the demand allocated.
	Scenario 2	For the user priority defined in Scenario 2, none of the demand is supplied at an assurance level of 1 in 20 years and the whole irrigation sector is prioritised at the 1 in 10-year risk of failure. There is no deficit between the demand and base yield.
	Scenario 1c (3)	For the user priority defined in Scenario 3, none of the demand is supplied at an assurance level of 1 in 20 years and the water required by the irrigation sector is prioritised 70% at the 1 in 10-year level of assurance and 30% at the 1 in 100 year respectively. There is no deficit between the demand and base yield.

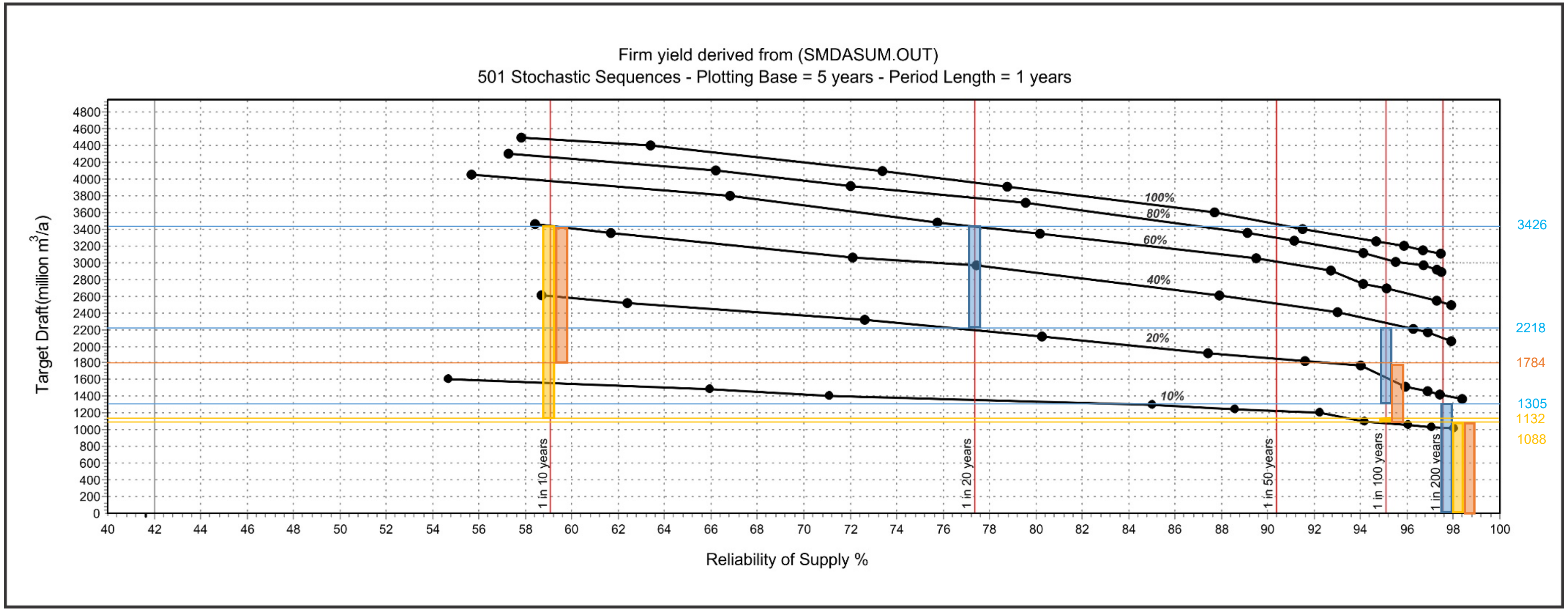


Figure 29: Orange River System short-term yield reliability curve with Polihali Dam

	Scenario 1	When the system storage is below 60%, it will fail to supply the full demand and use prioritised at a 1 in 20-year risk of failure will have to be restricted.
	Scenario 2	When the system storage is below 40%, it will fail to supply the full demand and use prioritised at a 1 in 10-year risk of failure will have to be restricted. The remaining use at a risk of failure of 1 in 200 years will only need to be restricted once the system storage is less than 10% at which a system yield of 1000 million m³ is available at a 98% reliability of supply.
	Scenario 1c (3)	When the system storage is below 40%, it will fail to supply the full demand and use prioritised at a 1 in 10-year risk of failure will have to be restricted. Use prioritised at a 1 in 100-year risk of failure will have to be restricted prior to the system reaching 20% at which point it only yields 1784 million m³.

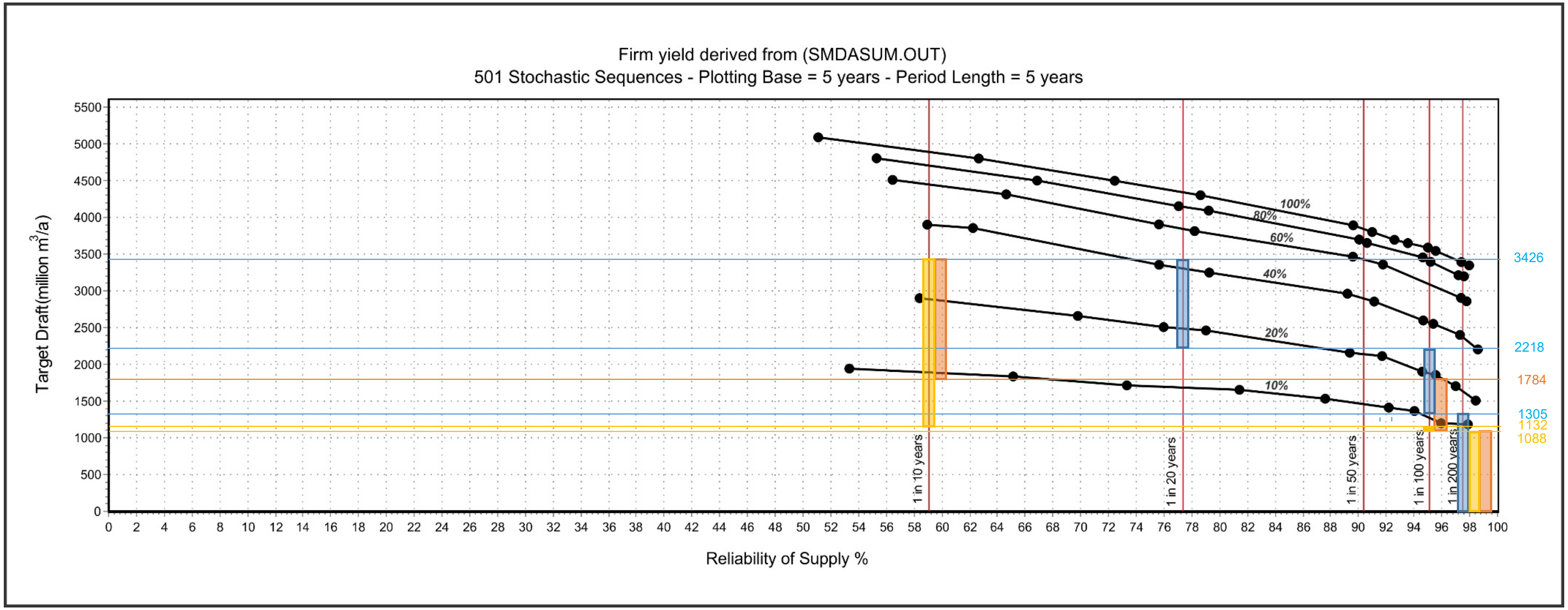


Figure 30: Orange River System short-term yield reliability curve without Polihali Dam

	Scenario 1	When the system storage is at 40%, it will fail to supply the full demand and use prioritised at a 1 in 20-year risk of failure will have to be restricted. The remaining use prioritised at a risk of failure of 1 in 100 year will already need to be restricted before the system storage decreases to 20%.
	Scenario 2	When the system storage is between 40% and 20%, it will fail to supply the full demand and use prioritised at a 1 in 10-year risk of failure will have to be restricted. The remaining use at a risk of failure of 1 in 200 years will only need to be restricted once the system storage is less than 10% at which a system yield of 1132 million m³ is available at a 98% reliability of supply.
	Scenario 1c (3)	When the system storage is between 40% and 20%, it will fail to supply the full demand and use prioritised at a 1 in 10-year risk of failure will have to be restricted. Use prioritised at a 1 in 100-year risk of failure will only need to be restricted once the system storage decreases to 20% at which point the system yields 1784 million m³.

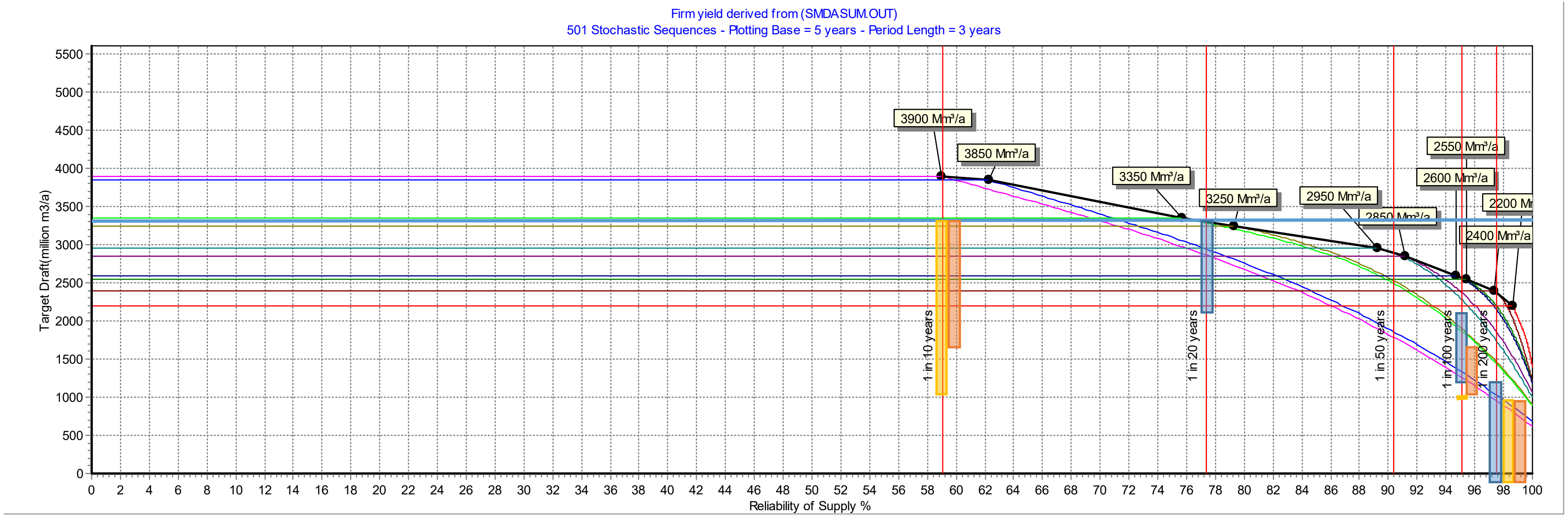


Figure 31: Orange River System 40% short-term yield reliability curve without Polihali Dam

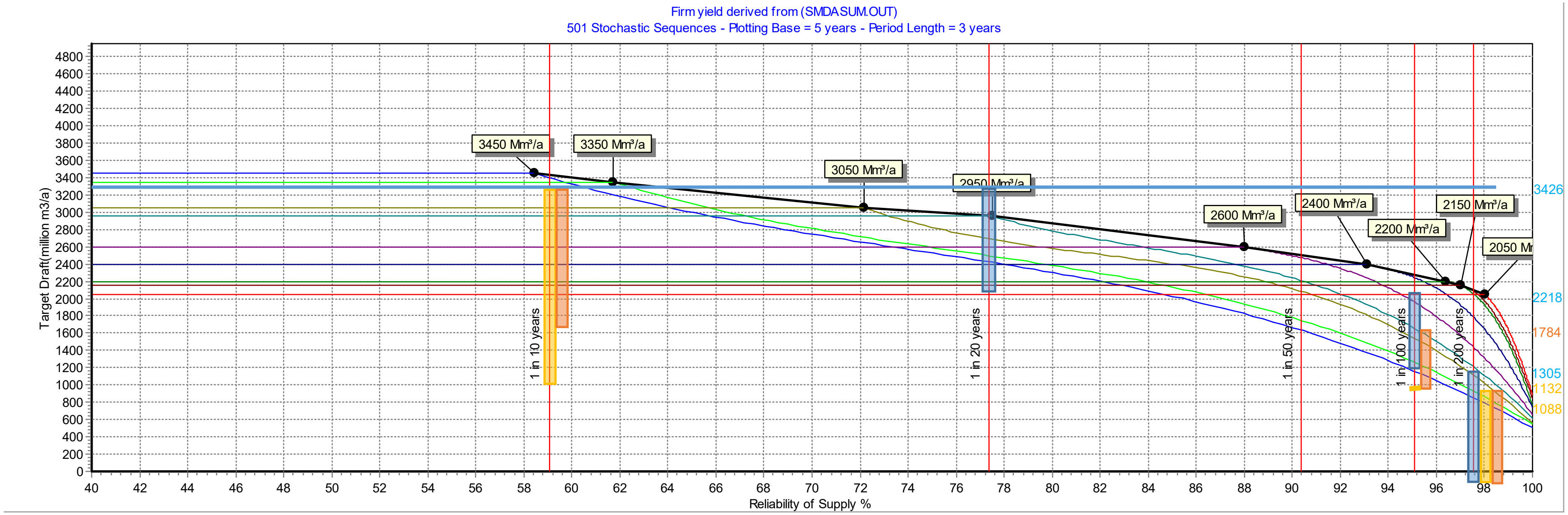


Figure 32: Orange River System 40% short-term yield reliability curve with Polihali Dam

The base condition assumptions adopted for the 2016/2017 scenario analysis are as follows:

1. **Starting conditions**: Based on actual dam storages as recorded on 2 May 2016.
2. **Storage control curves**: Storage control curves are used in both Gariep and Vanderkloof dams to prevent unnecessary spills from the dams by allowing maximum hydropower generation as soon as the water levels in the dam exceed the storage control level in the particular month. The storage control curves as used for the 2015/16 operating analysis will still apply for the 2016/17 operating analysis.
3. **Transfers to the Eastern Cape from Gariep Dam**: Transfers to the Eastern Cape were set equal to the actual water use licence (WUL) allocations (domestic demands) and agreed allocations (irrigation demands) excluding additional releases from Gariep Dam to cover losses in the Eastern Cape, but with growth included starting from 2016.
4. **The IVRS** is in place and analysed in combination with the Orange System with its updated demands, starting storages and other infrastructure related components as used for the 2016/2017 AOA of the IVRS.
5. **Lesotho Highlands Phase II (Polihali Dam)**: Polihali Dam was modelled to start storing water on 27 March 2023 and is used to support the IVRS from 22 November 2024 onwards. These are the most recent dates as obtained from the Lesotho Highlands Development Authority.
6. **Releases for environmental purposes**:

- Releases from Vanderkloof Dam to supply the Orange River Mouth requirement of 287.5 million m^3/a as determined in the ORRS were allowed in the analysis. This EWR is however based on outdated methods and needs to be updated at some time. Work in this regard was already done as part of the ORASECOM studies. Agreement on which environmental classes to be used to provide a balance between the environment and the economy of the supply area still needs to be obtained. This will require the involvement of all the basin states.
- Releases from Vanderkloof Dam to supply river requirements along the Orange River, which mainly comprise evaporation and evapotranspiration losses amounting to on average 615 million m^3/a, were included in the analysis.

7. **Neckartal Dam in Namibia**: Construction on the Neckartal Dam in the Fish River in Namibia has already started. For the purpose of the 2015/16 analysis, it was assumed that Neckartal Dam will start to impound water in December 2017 based on information received from Namibia. Neckartal Dam will not impact on the releases required from Vanderkloof Dam, but will reduce flows in the far Lower Orange, specifically during summer months, which previously would have entered the river mouth.

Table 34: Scenarios for Orange AOA 2016/2017

Scenario (WRPM reference)	Description
A	**Scenario A: Constant development level analysis used to determine discretional allocation to Eskom for power generation purposes (*this scenario was not analysed due to the current low storage levels in the dams*).** • **System analysed:** 10-year period. • **Reservoir start storage levels:** 2 May 2016 observed storage levels. • **Future dams:** Polihali and Neckartal dams excluded for the entire analysis period. • **Demands:** Latest updated 2016 demands (but with no growth over the analysis period i.e. constant development level). • **Eskom discretional allocation:** Included for the entire analysis period. • **DWS Northern Cape discretional allocation:** 100 million m³/a. • **Operating losses:** 80 million m³/a. • **Transfers to the Eastern Cape:** Set equal to the 2016 allocations (excluding additional releases from Gariep Dam to cover losses in the Eastern Cape).
Base Scenario	**Scenario B (Base Scenario): Projection analysis used to determine current and future assurance of supply violations, as well as storage projection plots and flow projection plots for the Orange River and Greater Bloemfontein bulk water supply (BWS) systems.** • **System analysed:** 10-year period. • **Reservoir start storage levels:** 2 May 2016 observed storage levels. • **Future dams:** Polihali and Neckartal dams included from March 2023 and December 2017 respectively. • **Demands:** Latest updated 2016 demands (with expected growth over the analysis period). • **Eskom discretional allocation:** 0 million m³/a included in all the years. • **DWS Northern Cape discretional allocation:** 100 million m³/a. • **Operating losses**: 80 million m³/a. • **Transfers to the Eastern Cape:** Set equal to the 2016 allocations (excluding additional releases from Gariep Dam to cover losses in the Eastern Cape).
B	**Scenario B: Used to determine the minimum releases from Gariep and Vanderkloof.** • **System analysed:** Three-year period. • **Reservoir start storage levels:** 2 May 2016 observed storage levels. • **Future dams:** Polihali and Neckartal dams included from March 2023 and December 2017 respectively. • **Demands:** Latest updated 2016 demands (with expected growth over the analysis period). • **Eskom discretional allocation:** 0 million m³/a. • **DWS Northern Cape discretional allocation:** 0 million m³/a. • **Operating losses:** 80 million m³/a. • **Transfers to the Eastern Cape:** Set equal to the 2016 allocations (excluding additional releases from Gariep Dam to cover losses in the Eastern Cape).
C	**Scenario C: Used to determine the impact of releases exceeding the target draft as occurred during the 2015/16 operating year.** Based on the **Base Scenario** with the following changes: • Allowing Eastern Cape losses to be supplied from Gariep Dam. • Allowing 20% higher releases into the Vanderkloof Canal System.

In terms of the development of scenarios to be analysed for this research study, it is important to remember the objective of the study and identify sensible scenarios to analyse. The scenarios analysed for the Orange AOA 2016/2017 planning year are a reflection of what is currently happening in practice and some of the results are readily available for interpretation. Furthermore, the two alternative options identified in the Orange Recon Study in terms of the user priority classification will serve as preliminary scenarios for further analyses in this research study. Scenario 1c – where 30% of the agricultural sector is supplied at a 99% assurance and 70% at a 90% assurance in terms of the priority classification definition – is in line with the split between the permanent (25%) and temporary (75%) crops identified in the Orange River as discussed in Section 4.3.1.3. Table 35 summarises the scenarios that have been identified and developed for preliminary analysis.

Table 35: Scenarios identified for analysis

<table>
<tr><th>Scenario for system analysis</th><th>Description</th><th colspan="3">User priority classification</th></tr>
<tr><td>Scenario A</td><td>Constant development level – 2016 demands</td><td rowspan="3">Scenario 1</td><td rowspan="3">Scenario 2</td><td rowspan="3">Scenario 3</td></tr>
<tr><td>Base Scenario</td><td>Projection scenario with growth included</td></tr>
<tr><td>Scenario C</td><td>Scenario 2 with additional demand volume for losses in Eastern Cape and 20% higher releases to Vanderkloof main canal</td></tr>
</table>

Table 36 shows the final references selected for the developed scenarios that will be used for the analyses in the Orange River System.

Table 36: Final reference adopted for scenarios to be analysed in the Orange River System

<table>
<tr><th>Scenario</th><th>Description</th><th colspan="3">User priority classification</th><th rowspan="10">⇨</th><th>Scenario</th></tr>
<tr><td rowspan="3">Scenario 1</td><td rowspan="3">Constant development level – 2016 demands (including Polihali Dam)</td><td rowspan="9">Original</td><td rowspan="9">Alternative A</td><td rowspan="9">Alternative B</td><td>Sc 1</td></tr>
<tr><td>Sc 1a</td></tr>
<tr><td>Sc 1b</td></tr>
<tr><td rowspan="3">Scenario 2</td><td rowspan="3">Projection scenario with growth included</td><td>Sc 2</td></tr>
<tr><td>Sc 2a</td></tr>
<tr><td>Sc 2b</td></tr>
<tr><td rowspan="3">Scenario 3</td><td rowspan="3">Scenario 2 with additional demand volume for losses in Eastern Cape and 20% higher releases to Vanderkloof main canal</td><td>Sc 3</td></tr>
<tr><td>Sc 3a</td></tr>
<tr><td>Sc 3b</td></tr>
</table>

The analyses will form part of an iterative process to find the best scenario among those identified and possible amendments thereof to cater for extreme probabilities. Table 37 lists the different priority classifications that were compared for the irrigation sector per level of curtailment.

Table 37: Orange River System irrigation curtailment proportions

User priority option	Risk curtailment levels	1/10	1/20	1/100	1/200	Total
Original	**Proportion**	–	0.5	0.4	0.1	**1**
	Volume (million m³)	–	1 046.5	837.2	209.3	**2 093**
Alternative A	**Proportion**	0.7	0	0.3	0	**1**
	Volume (million m³)	1 465.1	0	627.9	0	**2 093**
Alternative B	**Proportion**	1.0	0	0	–	**1**
	Volume (million m³)	2 093	0	0	–	**2 093**

4.3.1.5 *Scenario analyses*

The Base Scenario adopted for the analyses to be undertaken in this research study was the same scenario that was developed for the Orange River AOA. The volume of demands imposed on the Orange River System was that of the 2016/2017 development level. The first scenario analysed was based on a constant development level, which means that no growth in water requirement over the analysis period is considered. The second scenario referred to as the Base Scenario, takes growth into calculation for a period of 10 years. Due to the excessive actual use from the Orange River System monitored during the 2015/2016 operating year, it was decided to also undertake an analysis that would allow for irrigation distribution losses for the water supplied to the Eastern Cape from Gariep Dam as well as 20% higher releases into the Vanderkloof canal system. This would be more realistic and provide for the worst case in terms of low dam starting storage levels and possible curtailments to be imposed on the system. These scenarios are summarised in Table 38.

For all these scenarios, the impoundment of Polihali Dam, planned to start in 2022, was considered. The water requirement from the system is at the 2016 development level with no growth over the period of the analyses.

The combined storage of the Gariep and Vanderkloof dams as measured on the first of May 2016 was used for the three initial scenarios analysed. These volumes and for both dams and the percentage of the gross and nett full supply capacity (FSC) are listed in Table 39.

In addition to the scenario configuration defined in Table 38, it was decided to also amend the water allocation definition to the different user sectors. The motivation is to determine the assurance of supply requirements that would render results necessitating either smaller system curtailments or postpone the need for curtailments, or both.

Table 38: Scenarios for the Orange River System

Scenario (WRPM reference)	Description
Constant Development (Scenario 1)	**Constant Development Scenario: Based on Base Scenario with zero (0) growth in water requirements over the analysis period.**
Base Scenario (Scenario 2)	**Scenario B (Base Scenario): Projection analysis used to determine current and future assurance of supply violations, as well as storage projection plots and flow projection plots for the Orange River System and Greater Bloemfontein BWS systems.** • **System analysed:** 10-year period. • **Reservoir start storage levels:** 2 May 2016 observed storage levels. • **Future dams:** Polihali and Neckartal dams included from March 2023 and December 2017 respectively. • **Demands:** Latest updated 2016 demands (with expected growth over the analysis period). • **Eskom discretional allocation:** 0 million m³/a included in all the years. • **DWS Northern Cape discretional allocation:** 100 million m³/a. • **Operating losses**: 80 million m³/a. • **Transfers to the Eastern Cape:** Set equal to the 2016 allocations (excluding additional releases from Gariep Dam to cover losses in the Eastern Cape).

Scenario (WRPM reference)	Description
Constant Development (Scenario 1)	**Constant Development Scenario: Based on Base Scenario with zero (0) growth in water requirements over the analysis period.**
C (Scenario 3)	**Scenario C: Used to determine the impact of releases exceeding the target draft as occurred during the 2015/16 operating year.** **Based on the Base Scenario with the following changes:** • Allowing Eastern Cape losses to be supplied from Gariep Dam. • Allowing 20% higher releases into the Vanderkloof Canal System.

Table 39: Orange River System storage

Dam	Water in dam (million m³)	% of gross FSC [1]	% of nett FSC
Gariep	2 798.9	53.8%	47.6%
Vanderkloof	1 950.2	61.2%	43.0%
Orange River System	4 749.1	56.6%	46.1%

[1] Full supply capacity

Table 40 summarises the percentages at which the water requirement is supplied to the various user sectors at different assurance of supply levels for each of the options of user priority classification criteria applied. Table 41 to Table 43 show the corresponding volumes per user sector.

Table 40: Percentages of user sectors prioritised at different assurances

Water supply sector	% of the water demand to be supplied											
	High (99.5% assurance) 1 in 200 years			Medium high (99% assurance) 1 in 100 years			Medium low (95% assurance) 1 in 20 years			Low (90% assurance) 1 in 10 years		
Option	**ori[1]**	**a[2]**	**b[3]**	**ori**	**a**	**b**	**ori**	**a**	**b**	**ori**	**a**	**b**
Irrigation	10	0	0	40	30	0	50	0	0	0	70	100
Urban	50	unchanged		30	unchanged		20	0	0	0	20	20
Loss	100	unchanged		0	unchanged		0	unchanged		0	unchanged	
Environment	68	unchanged		0	unchanged		32	32	0	0	0	32

1: Original user priority classification 2: Alternative 13: Alternative 2

Table 41: Orange River user priority classification (Scenario 1)

Water supply sector	Volume of water demand to be supplied at given assurance in million m³				
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Medium (95% assurance) 1 in 20 year	Low (90% assurance) 1 in 10 years	Total
Irrigation	217.29	869.17	1 086.46	0	**2 172.92**
Urban/mining	72.96	43.78	29.18	0	**145.92**
Losses	819.15	0.00	0.00	0	**819.15**
Environmental	195.50	0.00	92.00	0	**287.50**
Total	**1 304.90**	**912.94**	**1 207.64**	**0**	**3 425.49**
Cumulative	**1 304.90**	**2 217.85**	**3 425.49**		

Table 42: Orange River user priority classification (Scenario 1a)

Water supply sector	Volume of water demand to be supplied at given assurance in million m³				
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Medium (95% assurance) 1 in 20 year	Low (90% assurance) 1 in 10 years	Total
Irrigation	0	651.88	0	1 521.04	**2 172.92**
Urban/mining	72.96	43.78	0	29.18	**145.92**
Losses	819.15	0	0	0	**819.15**
Environmental	195.50	0	92	0	**287.50**
Total	**1 087.61**	**695.65**	**92**	**1 550.24**	**3 425.49**
Cumulative	**1 087.61**	**1 783.26**	**1 875.26**	**3 425.49**	

Table 43: Orange River user priority classification (Scenario 1b)

Water supply sector	Volume of water demand to be supplied at given assurance in million m³				
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Medium (95% assurance) 1 in 20 year	Low (90% assurance) 1 in 10 years	Total
Irrigation	0	0	0	2 172.92	**2 172.92**
Urban/mining	72.96	43.78	0	29.18	**145.92**
Losses	819.15	0	0	0	**819.15**
Environmental	195.50	0	0	92.00	**287.50**
Total	**1 087.61**	**43.78**	**0**	**2 294.10**	**3 425.49**
Cumulative	**1 087.61**	**1 131.39**	**–**	**3 425.49**	

4.3.2 Groot Letaba River System

4.3.2.1 Background

The Letaba River Catchment is situated in the north-eastern part of the RSA, partly riparian to the Kruger National Park, consisting of the Groot Letaba River and its tributaries: the major ones include Klein Letaba, Middle Letaba, Letsitele and Molototsi River. The Letaba River receives a mean annual rainfall of ±612 mm. The Letaba WUA is the main WUA overseeing the other major commercial irrigation schemes of Ebenezer Dam, Magoebaskloof Dam, Hans Merensky Dam and Tzaneen Dam.

In 2015, a reconciliation strategy for the Luvuvhu and Letaba Water Supply System was developed (DWS, 2015b). Its main objective is to identify and describe water resource management interventions that can be grouped and phased to jointly form a solution to reconcile the water requirements with the available water for the period up to the year 2040 and to develop water availability assessment methodologies and tools applicable to this area that can be used for decision support as part of compulsory licensing to come. As part of achieving these objectives, the system models (WRSM2005, WRYM, WRPM) in the study area, at a quaternary catchment scale or finer, were configured in a manner that was suitable for allocable water quantification.

Figure 33 illustrates the catchment area of the Groot Letaba River with the Tzaneen Dam as major and main water resource. Transfers to other catchments are also indicated.

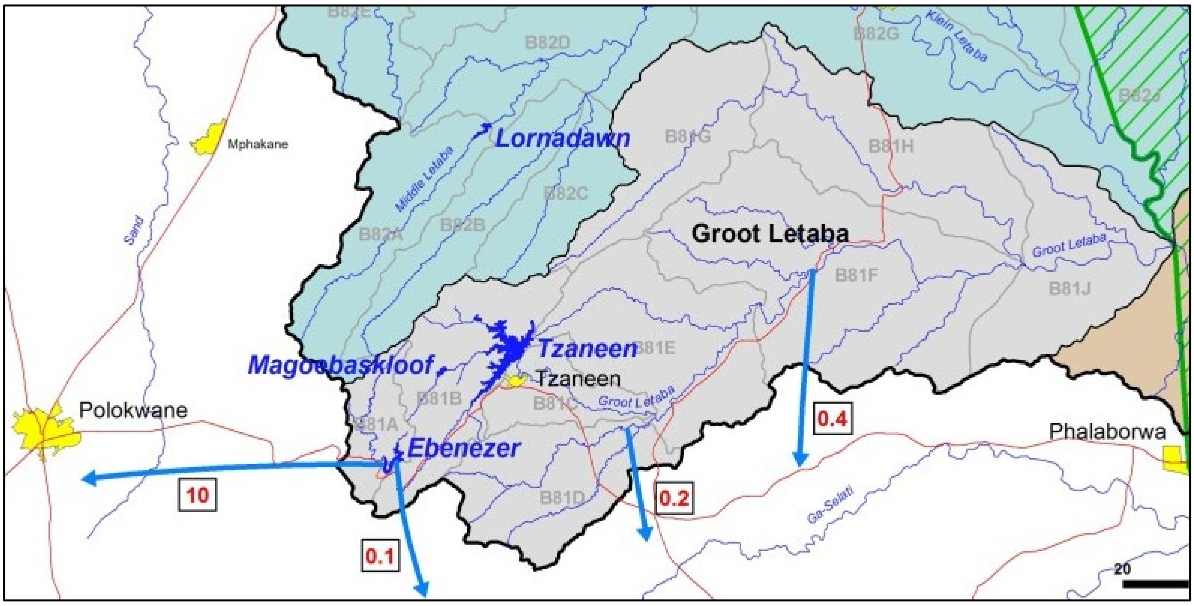


Figure 33: Groot Letaba River System

4.3.2.2 Water requirements

Irrigation agriculture is the largest surface water user sector in the Groot Letaba River System requiring 70% from the surface water resources. The Letaba WUA is the mother institution of several other WUAs, which include the commercial irrigation schemes of Ebenezer, Magoebaskloof, Hans Merensky and Tzaneen dams. There are six canals in the catchment through which water is conveyed to these schemes. These canals are listed in Table 44.

Table 44: Groot Letaba irrigation canals

Canal	Length (km)	Capacity (m^3/s)	Area (ha)	Quota (million m^3/a)	WRYM supply channel
George Valley	11	0.196	376	2.5	223
Pusela	29	1.06	997	7	229
Letaba North	43.2	2.6	951	27.8	687/688/689/159
N & N	35.4	1.59	1 278	13.3	98
Masalal	20	–	726	6.7	
Total	**138.6**		**4 328**	**57.3**	

The Groot Letaba River System was divided into five economic regions during the *Classification of Water Resources and Determination of the Resource Quality Objectives in the Letaba Catchment Study* in 2013 (DWA, 2013b). The water requirements populated for these areas were in line with the 2010 validation data as sourced from the water requirements and return flows report from the *Luvuvhu and Letaba Recon Study* (DWS, 2014b) and are indicated in Table 45 and Table 46.

Table 45: Groot Letaba irrigation areas per economic region (ha)

Region	Scheme			Diffuse			Total scheme and diffuse
	Canals	RoR[1]	Total	Surface	Ground	Total	
Region 1	1 686	506	2 192	2 688	402	3 090	5 282
Region 2	2 905	720	3 625	4 448	646	5 094	8 719
Region 3	4 727	961	5 689	3 284	1 872	5 156	10 844
Region 4	–	3 521	3 521	734	1 294	2 028	5 549
Region 5	–	–	–	625	138	763	763
Total	**9 318**	**5 708**	**15 027**	**11 779**	**4 352**	**16 131**	**31 158**

[1] Run-off river

Table 46: Groot Letaba irrigation volumes per economic region (million m^3/a)

Region	Scheme			Diffuse			Total scheme and diffuse
	Canals	RoR	Total	Surface	Ground	Total	
Region 1	10.1	1.9	11.9	17.9	2.7	20.6	32.5
Region 2	23.3	3.6	26.9	44.9	6.5	51.3	78.3
Region 3	27.9	4.8	32.7	37.8	21.5	59.4	92.1
Region 4	0	19.5	19.5	10	17.3	27.4	46.8
Region 5	0	0	0	4.5	2.5	7	7
Total	**61.3**	**29.7**	**91***	**115.1**	**50.5**	**165.6**	**256.6***

*RPFs not included (31.3 million m^3/a)

Note should be taken that the addition of RPFs after the construction of the planned Nwamitwa Dam (expected to commence in 2017) to the total irrigation water requirement is excluded from Table 46.

There were some discrepancies with the economic regions defined previously and the final excepted descriptions for the purpose of this study are listed in Table 47.

Table 47: Economic regions in the Groot Letaba River System

Economic region	Description	Quaternary catchment
Region 1	Above the Tzaneen Dam	B81A & B
Region 2	From the Tzaneen Dam to the confluence with the Letsitele River	B81C & D
Region 3	Nwamitwa Sub-catchment	B81E
Region 4	Below Nwamitwa Dam Upper Molototsi River	B81F & G
Region 5	Molototsi River	B81H & J

The irrigation requirements and areas from surface water resources for the 2014 development year (as sourced from the *Planning Analysis Report of the Luvuvhu and Letaba Recon Study*) are listed per channel configured for both water resource models in Table 49. The water requirement from groundwater resources are not considered when using the WIM; therefore, the groundwater channels configured in the WRYM will not be reviewed during the analyses to be carried out.

The Groot Letaba region is known for its tropical climate. Fruit and exotic crop production is prominent in this area. Table 48 lists some of the most common crops cultivated within the irrigation schemes in the Groot Letaba River System. The areas and volumes listed are specifically those that have been configured in the WRYM and WIM for analysis purposes.

Table 48: Irrigation in the Groot Letaba River System

Crops	Area (hectares)	Average water use (m^3/ha)	Volume (million m^3)
Maize	–	–	–
Soya beans	–	–	–
Dry beans	–	–	–
Industrial tomatoes	–	–	–
Fresh tomatoes	0.81	6 034	0
Potatoes	–	–	–
Summer vegetables	896	3 457	3.10
Winter vegetables	770	4 210	3.24
Wheat	–	–	–
Lucerne	–	–	–
Sugar cane	–	–	–
Bananas	666	6 238	4.16
Grapes – fresh	–	–	–
Grapes – wine	–	–	–
Grapes – dry	–	–	–
Macadamias	163	4 941	0.80
Citrus – oranges	5 720	5 861	33.52
Citrus – grapefruit	2 044	6 551	13.39
Avocados	2 949	6 525	19.24
Litchis	545	8 231	4.49
Deciduous fruit	–	–	–
Palm dates	–	–	–
Mangoes	1 528	6 629	10.13
Total	**15 283**		**92.08**

Table 49: Summary of system water requirement projections (million m^3/annum)

Resource	WRPM channel no.	Description	WRPM type	2014	2020	2025	2030	2035	2040
Groot Letaba River System				**Demands**					
Dap Naude Dam	202	Polokwane abstraction from Dap Naude	Master Control	4.00	4.00	4.00	4.00	4.00	4.00
Vergelegen Dam	167	Politsi, Duiwelskloof, Gakgapane	Master Control	2.34	2.62	2.86	3.10	3.35	3.61
Ebenezer Dam	220	Polokwane abstraction from Ebenezer	Min Max	16.17	16.17	16.17	16.17	16.17	16.17
Ebenezer Dam	66	Tzaneen Town	Min Max	2.38	2.58	2.74	2.89	3.04	3.20
Tzaneen Dam	68	Tzaneen Town	Min Max	1.28	1.28	1.28	1.28	1.28	1.28
Tzaneen Dam	543/995	Ritavi/Letaba regional water scheme (RWS)	Min Max	2.88	3.46	3.98	4.30	4.64	4.99
Tzaneen & Nwamitwa dams	69	Ritavi II RWS excl. Nkowankowa	Min Max	11.32	14.56	17.54	18.95	20.40	21.96
Tzaneen & Nwamitwa dams	686/996	Siluwane – Nondweni Extended RWS	Min Max	0.27	0.40	0.52	0.56	0.60	0.65
Tzaneen & Nwamitwa dams	885	Support to Tapane RWS	Min Max	0.00	0.38	0.69	0.91	1.14	1.38
Tzaneen & Nwamitwa dams	884	Support to Thabina RWS	Min Max	0.00	1.97	3.74	4.41	5.08	5.80
Tzaneen Dam	674	Industrial	Min Max	4.08	4.08	4.08	4.08	4.08	4.08
Thabina Dam	67	Thabina RWS Total (SW)	Master Control	4.33	4.30	4.30	4.30	4.30	4.30
Thapane Dam	901	Thapane RWS Total (SW)	Master Control	1.54	1.53	1.53	1.53	1.53	1.53
Support from Middle Letaba	886	Mojadji RWS	Master Control	0.00	0.00	0.94	1.33	1.73	2.16
Modjadji Dam	544	Mojadji RWS	Master Control	3.02	4.04	3.72	3.64	3.56	3.47
Groot Letaba Total Urban/industrial and Rural Domestic Requirements				**53.62**	**61.37**	**68.10**	**71.46**	**74.91**	**78.58**
Magoebaskloof Dam	900	Tea Plantation (growth uncertain)	Master Control	0.00	5.00	9.10	9.10	9.10	9.10
Magoebaskloof Dam	39	Politsi tea plantation scheme	Irrigation Block	3.20	3.20	3.20	3.20	3.20	3.20
Hans Merensky Dam	45	Westfalia Estates and other irrigators	Irrigation Block	4.51	4.51	4.51	4.51	4.51	4.51

Resource	WRPM channel no.	Description	WRPM type	2014	2020	2025	2030	2035	2040
Ebenezer Dam	189	Georges Valley Canal irrigation supply	Irrigation Block	0.50	0.50	0.50	0.50	0.50	0.50
Ebenezer Dam	187	Georges Valley Canal irrigation supply	Irrigation Block	0.42	0.42	0.42	0.42	0.42	0.42
Ebenezer Dam	185	Georges Valley Canal irrigation supply	Irrigation Block	1.40	1.40	1.40	1.40	1.40	1.40
Ebenezer Dam	183	Georges Valley Canal irrigation supply	Irrigation Block	0.22	0.22	0.22	0.22	0.22	0.22
Ebenezer Dam	195	Pusela Canal irrigation supply	Irrigation Block	2.08	2.08	2.08	2.08	2.08	2.08
Ebenezer Dam	197	Pusela Canal irrigation supply	Irrigation Block	4.19	4.19	4.19	4.19	4.19	4.19
Ebenezer Dam	199	Pusela Canal irrigation supply	Irrigation Block	0.36	0.36	0.36	0.36	0.36	0.36
Ebenezer Dam	193	Pusela Canal irrigation supply	Irrigation Block	0.37	0.37	0.37	0.37	0.37	0.37
Ebenezer Dam	191	Ebenezer M/S Scheme	Irrigation Block	0.72	0.72	0.72	0.72	0.72	0.72
Tzaneen Dam	346	Irrigation directly from Tzaneen Dam	Irrigation Block	0.92	0.92	0.92	0.92	0.92	0.92
Tzaneen Dam	104	Irrigation from River d/s of Tzaneen Dam	Irrigation Block	2.84	2.84	2.84	2.84	2.84	2.84
Tzaneen Dam	79	Irrigation from River d/s of Tzaneen Dam	Irrigation Block	2.10	2.10	2.10	2.10	2.10	2.10
Tzaneen Dam	71	Irrigation from River via Noord Canal d/s of Tzaneen Dam	Irrigation Block	4.36	4.36	4.36	4.36	4.36	4.36
Tzaneen Dam	160	Irrigation from River via Noord Canal d/s of Tzaneen Dam	Irrigation Block	2.78	2.78	2.78	2.78	2.78	2.78
Tzaneen Dam	81	Irrigation from River via Noord Canal d/s of Tzaneen Dam	Irrigation Block	12.32	12.32	12.32	12.32	12.32	12.32
Tzaneen Dam	517	Irrigation from River via Noord Canal d/s of Tzaneen Dam	Irrigation Block	9.34	9.34	9.34	9.34	9.34	9.34
Tzaneen Dam	85	Irrigation from River via N&N Canal d/s of Tzaneen Dam	Irrigation Block	3.42	3.42	3.42	3.42	3.42	3.42
Tzaneen Dam	519	Irrigation from River via N&N Canal d/s of Tzaneen Dam	Irrigation Block	9.61	9.61	9.61	9.61	9.61	9.61

Resource	WRPM channel no.	Description	WRPM type	2014	2020	2025	2030	2035	2040
Tzaneen Dam	83	Irrigation from River d/s of Tzaneen Dam	Irrigation Block	0.74	0.74	0.74	0.74	0.74	0.74
Tzaneen Dam	344	Irrigation from River d/s of Tzaneen Dam	Irrigation Block	0.34	0.34	0.34	0.34	0.34	0.34
Tzaneen Dam	375	Irrigation from River d/s of Tzaneen Dam	Irrigation Block	2.22	2.22	2.22	2.22	2.22	2.22
Tzaneen & Nwamitwa dams	379	Irrigation from River at Nwamitwa Dam	Irrigation Block	2.22	2.22	2.22	2.22	2.22	2.22
Tzaneen & Nwamitwa dams	405	Irrigation from River d/s Nwamitwa Dam	Irrigation Block	4.75	4.75	4.75	4.75	4.75	4.75
Tzaneen & Nwamitwa dams	403	Irrigation from River d/s Nwamitwa Dam	Irrigation Block	3.09	3.09	3.09	3.09	3.09	3.09
Tzaneen & Nwamitwa dams	545	Irrigation from River d/s Nwamitwa Dam	Irrigation Block	2.23	2.23	2.23	2.23	2.23	2.23
Tzaneen & Nwamitwa dams	411	Irrigation from River d/s Nwamitwa Dam	Irrigation Block	2.18	2.18	2.18	2.18	2.18	2.18
Tzaneen & Nwamitwa dams	902	Irrigation from River d/s Nwamitwa Dam	Master Control	31.33	31.33	31.33	31.33	31.33	31.33
Tzaneen & Nwamitwa dams	425	Irrigation from River d/s Nwamitwa Dam	Irrigation Block	0.47	0.47	0.47	0.47	0.47	0.47
Tzaneen & Nwamitwa dams	427	Irrigation from River d/s Nwamitwa Dam	Irrigation Block	0.47	0.47	0.47	0.47	0.47	0.47
Tzaneen & Nwamitwa dams	431	Irrigation from River at Nondweni Weir	Irrigation Block	3.27	3.27	3.27	3.27	3.27	3.27
Tzaneen & Nwamitwa dams	433	Irrigation from River d/s Nondweni Weir	Irrigation Block	0.47	0.47	0.47	0.47	0.47	0.47
Tzaneen & Nwamitwa dams	435	Irrigation from River d/s Nondweni Weir	Irrigation Block	2.57	2.57	2.57	2.57	2.57	2.57
Groot Letaba Total Irrigation Requirements				**122.00**	**127.00**	**131.10**	**131.10**	**131.10**	**131.10**
Groot Letaba Total Surface Water Requirements				**175.62**	**188.37**	**199.20**	**202.56**	**206.01**	**209.68**

Table 50 categorises the different irrigation crops cultivated in the Groot Letaba River System. Up to 74% of the crops are permanent and 26% are temporary. This emphasises the importance of developing restriction rules that will not only prevent the water resource from failing, but also the permanent crops in the irrigation agriculture sector from reaching wilting point.

Table 50: Crop type distribution percentage in the Groot Letaba River System

Crop	Percentage (%)	Type	Percentage (%)
Maize	1.2%	Temporary	25.9%
Summer vegetables	7.3%		
Winter vegetables	8.3%		
Industrial tomatoes	1.7%		
Fresh tomatoes	7.4%		
Macadamias	2.2%	Permanent	74.1%
Citrus	20.9%		
Bananas	7.3%		
Avocadoes	16.3%		
Litchis	10.1%		
Mangoes	2.6%		
Deciduous fruit	14.7%		

4.3.2.3 Scenario development

For the purpose of the water balances, domestic water use was supplied at a 98% assurance (drought recurrence interval 1 in 50 years). Irrigation was supplied at 90% assurance (drought recurrence interval of 1 in 10 years). Table 51 indicates the user priority criteria defined for the Groot Letaba River System.

Table 51: Groot Letaba River System user priority classification

Water supply sector	Priority classification			
	High (99.5% assurance) 1 in 200 year	Medium high (99% assurance) 1 in 100 year	Medium low (98% assurance) 1 in 50 year	Low (90% assurance) 1 in 10 years
Irrigation	0	0	0	100
Urban	0	0	100	0
Losses	100	0	0	0

These assurances need to be clarified with the users as some of the urban and rural domestic use can be supplied at a higher assurance and some at a lower assurance than the 98% used in all the analyses carried out for this study. The same also applies to the irrigation sector. Applying a more detailed user priority classification to the model will also affect the water supply situation and implementation dates of future intervention options. It was decided to either simulate the dams and sub-systems using the short-term curve restriction rules or the existing operating rules used in practice, depending on the existence of such rules.

As result of the overuse of the Groot Letaba System, severe and complicated restriction rules were developed and implemented by users. One rule, for example, requires that the irrigators are cut to 50% of their allocations once Tzaneen Dam drops to below 98.3%. This rule equates to a 68% supply on average to the irrigators, and 99% to urban use with the irrigation requirement representing more than 80% of the total demand imposed on the system. To ensure that the irrigators in the Groot Letaba

System still receive at least their current assurance of supply in future, it was decided to use the Groot Letaba existing restriction rules in the WRPM analysis for all related Groot Letaba analyses. For the remainder of the systems, the short-term stochastic yield characteristics were used as the basis of the operating rules.

The Groot Letaba Main System water balance contains the following proposed intervention options:

- WC/WDM saving 0.8 million m^3/a in urban sector (to be in place by 2015).
- Irrigation restriction policy to reduce the average irrigation water use. This is an existing policy that was developed by irrigation users to protect the resources. This option reduces the average irrigation water use to approximately 38% below the full allocation.
- The raising of Tzaneen Dam by 2017 resulting in an increased assurance of supply and a yield increase of 1 million m^3/a.
- Construction and implementation of Nwamitwa Dam by 2019 adding 5.5 million m^3/a to the high assurance yield and 0.7 million m^3/a to the low assurance yield.
- Additional groundwater development, increasing the system yield by at least 2.5 million m^3/a by 2018.
- To be able to protect the environment, the classification study agreed EWRs need to be implemented once Nwamitwa Dam is in place (2020)

Table 52 lists the new dams proposed to be constructed in the Groot Letaba River System.

Table 52: Proposed dams for Groot Letaba River System

Dam name	Sub-catchment	WRYM no.	FSV[1] (million m^3)	DSV[2] (million m^3)	FSA[3] (km^2)
Proposed Nwamitwa L	B81E10	265	186.60	0	25.00
Proposed Letsitele L	B81D2	87	28.90	0	2.26
Proposed Crystalfontein L	B82F	203	117.75	20.30	14.92
Proposed Majosi L	B82F	500	31.10	11.08	5.11

[1] FSV – Full supply volume, [2] DSV – Dead storage volume, [3] FSA – Full supply area

For the base tests to confirm that the system was operating correctly, the WRYM was configured to closely mimic the current operating rules between dams and restriction rules for users. However, for the purpose of yield analysis, these rules were not always considered: the purpose of the analysis was to determine the maximum yield from the various resources. The general rules are described in the following sub-sections, with specific details per scenario explained in the yield analysis scenario descriptions.

No upstream dam supports a downstream dam, except in the following cases:

- Ebenezer Dam was set to support Tzaneen Dam when Tzaneen Dam reached a 15% operating level.
- Dap Naude has a court order release schedule, which is currently not implemented. The required releases are that 0.028 m^3/s be released from the dam in the months from November to July, and that all inflows to the dam be released in August, September and October.

Restriction rules

Complex restriction rules apply to users obtaining water from Ebenezer and Tzaneen dams:

- **Tzaneen Dam urban users:** The existing rule for urban users is that they are allowed their full allocation until Tzaneen Dam reaches a 15% storage level, at which time they are restricted to 70% of their allocation. When testing this rule, it was shown to be too strict, and the dam was not fully used when the rule was implemented. The 15% level was dropped to 5%, and the dam was used more efficiently.
- **Tzaneen Dam irrigators:** Irrigators from Tzaneen Dam only obtain their full allocation when the dam is above 98.3%. The irrigators are cut to 50% of their allocation when the dam is below 95%, and are cut to zero when the dam reaches 15%. The irrigators are allocated 60% of their allocation between 95% and 96.7% dam levels and 70% of their allocation between 96.7% and 98.3% dam levels. When testing this rule, it was shown to be too strict, and the dam was not fully used when the rule was implemented. The zero allocation at 15% level was dropped to 5%, and the dam was used more efficiently.
- **Ebenezer Dam urban users:** The existing rule for urban users is that they are allowed their full allocation until Ebenezer Dam reaches a 20% storage level, at which time they are restricted to 70% of their allocation.
- **Ebenezer Dam irrigations:** The Ebenezer irrigators are restricted based on the same restrictions and storage levels of Tzaneen Dam; however, additionally, they are restricted to 0% of their allocation if Ebenezer Dam reaches 20% operating level.
- **Users from proposed Nwamitwa Dam:** The irrigators and urban users that fall downstream of Nwamitwa Dam were still restricted based on the rule of Tzaneen Dam.

These restrictions rules are summarised in Table 53.

Table 53: Summary of restriction rules in Groot Letaba River System

Source	User sector	Dam storage %	Restriction %
Tzaneen Dam	Urban	100	0
		15	30 (too strict)
		5	30
	Irrigation	≥ 98.3	0
		96.7–98.3	30
		95–96.7	40
		≤ 95	50
		15	100 (too strict)
		5	100
Ebenezer Dam	Urban	≤ 20	30
	Irrigation	≤ 20	100
Downstream Nwamitwa	Restricted based on the rule of Tzaneen Dam		

Run control settings in the WRYM are used to define general information on how the system will be analysed for a particular model run. For the yield analysis of the study area, this includes, most importantly, the following:

- An analysis period of 91 years from the 1920 to the 2010 hydrological year (i.e. October 1920 to September 2011) was used. This corresponds with the selected study period as well as with the updated and extended hydro-meteorological data sets developed during the hydrological analysis of the study.
- The long-term stochastic yield analyses were undertaken using the `PARAM.DAT` file developed as part of the stochastic streamflow analysis and based on 201 (91-year) stochastically generated streamflow sequences.
- The short-term stochastic yield analyses were undertaken based on 501 (five-year) stochastically generated streamflow sequences.

Regarding the short-term stochastic yield analyses mentioned above, it should be noted that such analyses are undertaken for the purpose of deriving short-term yield reliability characteristics of defined sub-systems within the system under consideration.

Table 54 lists the HFY analyses scenarios conducted, with the key scenarios highlighted in blue. Many of the analyses were carried out in the traditional manner of determining an HFY by removing all demands from the resource, and determining the resource capability under historical conditions. However, Tzaneen Dam cannot accurately be assessed in this manner as many of the users supplied from Tzaneen Dam are located further downstream in the catchment; therefore, they have additional access to incremental run-off occurring intermediately. It is more beneficial to monitor supply to the users in order to gain an understanding of the yield capabilities of the total system. Details of such an approach are provided in Table 54.

Table 54: HFY analyses scenario descriptions

Scenario ref.	Resource yield	Yield channel position	Details	Purpose of scenario
Aiii	Dap Naude	123	Excluding court order.	To determine yield of Dap Naude resource.
Aiv	Dap Naude	123	Including court order.	To determine impact of court order on Dap Naude.
Bi	Ebenezer	130	Included demand of 4 million m^3/a at Dap Naude Dam, excluding Dap Naude court order.	To determine yield of Ebenezer resource.
Bii	Ebenezer	130	Included demand of 4 million m^3/a at Dap Naude Dam, including Dap Naude court order.	To determine impact of Dap Naude court order on Ebenezer Dam.
Biii	Dap Naude and Ebenezer	Node 800	Included abstraction of 4 million m^3/a at Dap Naude Dam contributing to yield node, excluding Dap Naude court order, open channel from Ebenezer.	To determine combined yield of Dap Naude and Ebenezer Dams.
C	Magoebaskloof	6	No flow allowed to enter canal to Vergelegen.	To determine yield of Magoebaskloof resource alone.

Scenario ref.	Resource yield	Yield channel position	Details	Purpose of scenario
Di	Magoebaskloof and Vergelegen	7	Current irrigation (4.6 million m^3/a) abstracted from canal, additional yield from Vergelegen.	To determine yield/supply of Magoebaskloof–Vergelegen combination.
Diii	Magoebaskloof and Vergelegen	7	Previous irrigation (13.4 million m^3/a) abstracted from canal, additional yield from Vergelegen, canal capacity in place.	To determine yield/supply of Magoebaskloof – Vergelegen combination.
Div	Magoebaskloof and Vergelegen	Node 800	Included abstraction of 13.4 million m^3/a from canal contributing to yield node, open channel from Vergelegen.	To determine yield of Magoebaskloof–Vergelegen combination.
E	Hans Merensky	20		To determine yield of Hans Merensky.
F	Thabina	93		To determine yield of Thabina.
G	Tapane	269		To determine yield of Tapane.
H	Modjadji	287		To determine yield of Modjadji.
I	Middle Letaba	172	No flow allowed to enter canal to Nsami.	To determine yield of Middle Letaba.
J	Nsami	177	No support through canal from Middle Letaba.	To determine yield of Nsami.
Ji	Middle Letaba and Nsami	Node 800	Included abstraction of 2.8 million m^3/a at Nsami Dam contributing to yield node, open channel from Middle Letaba. Ground-water modelled explicitly, no canal losses included.	To determine yield of Middle Letaba–Nsami combination.
Jii	Middle Letaba and Nsami	Node 800	Ji including reduced incremental hydrology files u/s of Middle Letaba due to groundwater abstractions.	To determine impact in WRYM of modelling groundwater explicitly and using reduced hydrology files.
Ki	Tzaneen	42	No supply to users from Tzaneen, traditional HFY analysis.	To determine yield of Tzaneen Dam alone.
Kii	–	–	Abstractions by users at their specific locations, zero yield removed from Tzaneen Dam.	To determine total system capabilities including incremental run-off between Tzaneen Dam and users, to determine non-firm yield.

Scenario ref.	Resource yield	Yield channel position	Details	Purpose of scenario
Kii RP	–	–	As Kii.	To view impact of resource-poor allocation on users.
Li	Tzaneen	42	Raised Tzaneen Dam.	To determine yield of raised Tzaneen Dam alone.
Li 2	Tzaneen	42	Li with the current abstractions from Ebenezer Dam and support from Ebenezer Dam to Tzaneen Dam.	To determine benefit of Ebenezer support at Tzaneen.
Lii	–	–	Abstractions by users at their specific locations, zero yield removed from Tzaneen Dam.	To determine total system capabilities including incremental run-off between Tzaneen Dam and users, to determine non-firm yield.
Lii 2	**–**	–	**Lii with the current abstractions from Ebenezer Dam and support from Ebenezer Dam to Tzaneen Dam.**	**To determine benefit of Ebenezer support at Tzaneen on user supply.**
M	Tzaneen and proposed Nwamitwa	–	Abstractions by users at their specific locations, determined abstraction from Tzaneen Dam and Nwamitwa Dam until supply to users violated current requirements.	To determine improvements due to Nwamitwa Dam (live: 186.6 million m^3).
M 2	Tzaneen and proposed Nwamitwa	–	Scenario M with support from Ebenezer and Ebenezer demands abstracted, Ebenezer restriction rule in place, Nwamitwa dam-operating rule in place.	To determine system supply including support from Ebenezer.
Ni	Tzaneen and proposed Nwamitwa	–	Scenario M including low present ecological state (PES) EWRs for Sites 3, 4 and 5.	To determine impact of low PES EWRs on system.
Ni 2	Tzaneen and proposed Nwamitwa		Scenario M2 including Recommended EWR scenario from classification study, low PES EWRs for Sites 3, 4 and 5, and three high-flow PES releases per annum.	To determine impact of recommended EWRs on system.

Scenario ref.	Resource yield	Yield channel position	Details	Purpose of scenario
O	–	–	Scenario N including Letsitele Valley Dam and EWR Site 2.	To determine impact of inclusion of Letsitele Valley Dam (live: 28.9 million m^3) and EWR Site 2 would have on system.
Pi	Proposed Crystalfontein	203		To determine the yield of Crystalfontein Dam (Gross: 117.75 million m^3, dead: 20.3 million m^3).
Pii	Proposed Crystalfontein	203	Pi Including EWR Site 5.	To determine impact of EWR Site 5 on Crystalfontein Dam.
Piv	Majosi and Middle Letaba	172		To determine the combined yield of the proposed Majosi Dam (Gross: 31.1 million m^3, dead: 11.08 million m^3) and Middle Letaba.
Pv	Majosi and Middle Letaba	172	Pi Including EWR Site 5.	To determine impact of EWR Site 5 on the combination of the proposed Majosi Dam and Middle Letaba.

For Scenarios K, L, M and N, the greater of the HFY and the 2013 demand was abstracted from the upstream dams:

- Dap Naude: demand 4 million m^3/a
- Ebenezer: HFY 32 million m^3/a
- Magoebaskloof and Vergelegen: demand 13.4 million m^3/a and HFY 2.3 million m^3/a
- Hans Merensky: demand 4.2 million m^3/a
- Thabina: demand 2.8 million m^3/a
- Tapane: demand 1.2 million m^3/a
- Modjadji: demand 2.9 million m^3/a

HFY analyses results

Table 55 presents the HFY analyses results.

Table 55: HFY results

Scenario ref.	Resource yield	HFY	Details
Aiii	Dap Naude	3.1	
Aiv	Dap Naude	2.1	
Bi	Ebenezer	32	The average supply to irrigators from Ebenezer Dam was 6 million m^3/a after the firm 32 million m^3/a was abstracted from the dam. This is considered the non-firm portion.
Bii	Ebenezer	33.9	

Scenario ref.	Resource yield	HFY	Details
Biii	Dap Naude and Ebenezer	36.2	
C	Magoebaskloof	7.2	
Di	Magoebaskloof and Vergelegen	3.5	The average supply to the irrigation demand on the canal was 4.6 million m^3/a when the firm 3.5 million m^3/a was abstracted from the Vergelegen Dam.
Diii	Magoebaskloof and Vergelegen	0.2	The average supply to the irrigation demand on the canal was 13.1 million m^3/a when the firm 0.2 million m^3/a was abstracted from the Vergelegen Dam.
Div	Magoebaskloof and Vergelegen	8.1	
E	Hans Merensky	1.0	
F	Thabina	3.1	
G	Tapane	1.1	
H	Modjadji	3.5	
I	Middle Letaba	18.8	
J	Nsami	0.2	
Ji	Middle Letaba and Nsami	20.7	
Jii	Middle Letaba and Nsami	20.6	Modelling groundwater explicitly has a small impact of 0.1 million m^3/a on the system.
Ki	Tzaneen	44	
Kii	–	–	The total average supply was 65.9 million m^3/a to users, 49.4 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 68% supply to irrigators and 99% supply to urban.
Kii RP	–	–	The total average supply was 81.7 million m^3/a to users, 65.6 million m^3/a to irrigators and 16.1 million m^3/a to urban. This equates to 60% supply to irrigators and 97% supply to urban.
Li	Tzaneen	45	
Li 2	Tzaneen	50	
Lii	–	–	The total average supply was 82.6 million m^3/a to users, 66.4 million m^3/a to irrigators and 16.2 million m^3/a to urban. This equates to 61% supply to irrigators and 97% supply to urban.
Lii 2	**–**	**–**	**The total average supply was 85.7 million m^3/a to users, 69.3 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 67% supply to irrigators and 99.6% supply to urban.**

Scenario ref.	Resource yield	HFY	Details
M	Tzaneen and proposed Nwamitwa		The total average supply was 84.5 million m^3/a to existing users, 68.1 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 67% supply to irrigators and 99% supply to urban. An additional 15.5 million m^3/a could be abstracted from Tzaneen Dam and 0.5 million m^3/a from Nwamitwa Dam, bringing the total average supply of the scenario to 100.5 million m^3/a. The addition of Nwamitwa Dam added a total of 17.9 million m^3/a to the system.
M 2	Tzaneen and proposed Nwamitwa		The total average supply was 86.4 million m^3/a to existing users, 69.9 million m^3/a to irrigators and 16.5 million m^3/a to urban. This equates to 66.7% supply to irrigators and 98.8% supply to urban. An additional 24 million m^3/a could be abstracted from Tzaneen Dam, bringing the total average supply of the scenario to 110.4 million m^3/a. The support from Ebenezer Dam added a total of 9.9 million m^3/a to the system.
Ni	Tzaneen and proposed Nwamitwa		The total average supply was 85.7 million m^3/a to existing users, 69.3 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 65% supply to irrigators and 99% supply to urban. An additional 4 million m^3/a could be abstracted from Tzaneen Dam and there was no additional from Nwamitwa Dam, bringing the total average supply of the scenario to 89.7 million m^3/a. The inclusion of the low PES EWRs dropped the total supply of the system by 10.9 million m^3/a.
Ni 2	Tzaneen and proposed Nwamitwa		The total average supply was 87.1 million m^3/a to existing users, 70.7 million m^3/a to irrigators and 16.3 million m^3/a to urban. This equates to 66.7% supply to irrigators and 97.9% supply to urban. An additional 5 million m^3/a could be abstracted from Tzaneen Dam and there was no additional from Nwamitwa Dam, bringing the total average supply of the scenario to 92 million m^3/a. The inclusion of the recommended EWRs dropped the total supply of the system by 18.4 million m^3/a.
O	–		The total average supply was 84.7 million m^3/a to existing users, 68.3 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 64.5% supply to irrigators and 98.5% supply to urban. An additional 12 million m^3/a could be abstracted from Tzaneen Dam and 0.5 million m^3/a from Nwamitwa Dam, bringing the total average supply of the scenario to 97.2 million m^3/a. The inclusion of Letsitele Valley Dam and EWR 2 improved the system supply by 7.5 million m^3/a. However, the Letsitele irrigators supply drops from 22.9 million m^3/a to 19.7 million m^3/a as a result of EWR 2's requirements.

Scenario ref.	Resource yield	HFY	Details
Pi	Proposed Crystalfontein	6	
Pii	Proposed Crystalfontein	5.4	
Piv	Majosi and Middle Letaba	23.5	
Pv	Majosi and Middle Letaba	22.6	

Long-term stochastic yield analysis results

Table 56 presents the long-term stochastic yield analysis results for the selected scenarios described in Table 55**.** The long-term stochastic yields were determined using a starting storage of 50% for all the dams. These are considered the key yield results from the analyses. Additional analyses were undertaken for the Tzaneen system excluding (Scenario Lii 2 LT) and including (Scenario M 2 LT) Nwamitwa Dam, without and with the EWR (Scenario Ni 2 LT).

A different approach was followed to determine the yield or water supply capability of the Groot Letaba System (Tzaneen, Ebenezer and future Nwamitwa Dam) due to its total overallocation and the existing operating rule that is used to protect this resource from complete failure. The firm yield from this system is far less than the demand imposed on this system and supply to the current users was therefore evaluated, with the existing operating rule in place.

Table 56: Long-term stochastic yield results

Scenario ref.	Resource yield	HFY	1 in 20	1 in 50	1 in 100	1 in 200
Aiv	Dap Naude	2.1	3.1	2.6	2.4	2.1
Biii	Dap Naude and Ebenezer	36.2	43.8	40.5	37.2	34.7
Div	Magoebaskloof and Vergelegen	8.1	11.4	9.9	9.1	8.4
E	Hans Merensky	1.0	2.2	1.7	1.3	1.1
F	Thabina	3.1	4.1	3.7	3.4	3.2
G	Tapane	1.1	1.6	1.4	1.3	1.2
H	Modjadji	3.5	4.4	3.8	3.4	3.2
Jii	Middle Letaba and Nsami	20.6	31.0	24.3	21.5	18.6
Li	Tzaneen	45	60.0	51.7	45.5	40.4

For these analyses, the supply to all users was monitored, and the average supply to users was determined. Risk analysis were carried out using a stochastic approach. Table 57 and Table 58 present the results at different levels of assurance for the total minimum supply and the average supply to all users per stochastic sequence. These results show that even the low assurance of 95% (1 in 20 year) is much less than the historical average supply to the users, with the average supply only providing approximately 67% of the full water requirement for the irrigators and 99% of the urban/industrial requirements. The percentage of the total water requirements that could be supplied is indicated in brackets for each scenario. The total water requirement varies among the scenarios as per the descriptions listed in the details column in Table 55.

Table 57: Long-term stochastic results (minimum supply)

Scenario ref.	Resource yield	Historical supply (average)	Minimum supply in worst year			
			1 in 20	1 in 50	1 in 100	1 in 200
Lii 2 LT	**Tzaneen (supported by Ebenezer)**	**85.7 (71.5%)**	**66.1 (55.1%)**	**63.6 (53%)**	**59.5 (49.6%)**	**37.3 (31.1%)**
M 2 LT	Tzaneen (supported by Ebenezer) and Nwamitwa	110.4 (90.9%)	88.2 (72.6%)	85.0 (70%)	81.2 (66.8%)	56.9 (46.8%)
Ni 2 LT	Tzaneen (supported by Ebenezer) and Nwamitwa including EWR	92.0 (75%)	71.3 (58.1%)	68.2 (55.6%)	55.6 (45.3%)	25.5 (20.8%)

Table 58: Long-term stochastic results (average supply)

Scenario ref.	Resource yield	Historical supply (average)	Average supply in all years			
			1 in 20	1 in 50	1 in 100	1 in 200
Lii 2	**Tzaneen (supported by Ebenezer)**	**85.7 (71.5%)**	**93.3 (77.8%)**	**88.0 (73.4%)**	**86.0 (71.7%)**	**84.5 (70.5%)**
M 2	Tzaneen (supported by Ebenezer) and Nwamitwa	110.4 (90.9%)	117.5 (96.7%)	110.6 (91%)	108.1 (89%)	106.0 (87.2%)
Ni 2	Tzaneen (supported by Ebenezer) and Nwamitwa including EWR	92.0 (75%)	103.0 (84%)	95.4 (77.8%)	92.3 (75.3%)	89.5 (73%)

Figure 34 and Figure 35 present the long-term curves for the Tzaneen system. For these scenarios, a total additional amount of 17 million m^3/a was abstracted from Tzaneen Dam and 4 million m^3/a was abstracted from Nwamitwa Dam for Scenario M 2 LT; 5 million m^3/a was abstracted from Tzaneen Dam for Scenario Ni 2 LT. These yield results were used as input to the water balances that formed part of the reconciliation strategy prepared as the main output from this study.

The Groot Letaba Main System WRPM analysis in general provided similar results to those obtained from the long-term yield analyses and related water balances. The main differences are that the Nwamitwa Dam takes a long time to stabilise (approximately 8–10 years); therefore, it will not be able to deliver its full yield within one or two years after inundation starting. The assurance of supply to the urban and rural domestic users was in general lower than the 98% (1 in 50 year) used for the water balances. In general, 85% of the Tzaneen Demand is supplied at an assurance of 98% (1 in 50 year) and the assurance of supply started to decrease from 2033 onwards. The upper 50% of the irrigation requirements were supplied at a low assurance due to the restriction rule used and the lower 50% at a reasonably good assurance for irrigation purposes, similar to that obtained for the domestic supply.

Due to the complicated restriction rules currently used for the Groot Letaba System, which were also adopted in the WRPM, it was not possible to always obtain the same assurance of supply to all users within the same priority class as would be possible when short-term stochastic yield characteristics were used as the basis for the operating rule. Further refinement of this operating rule are required for future analysis to obtain an improved balance in the supply assurance and to protect the dams against total failure.

The water balance as used for the reconciliation strategy indicated that a positive water balance could only be achieved up to 2030. The WRPM analysis results showed a reduction in the assurance of supply from about 2033/2034 onwards. Further refinement of the priority classification can contribute to an improved water supply over the analysis period.

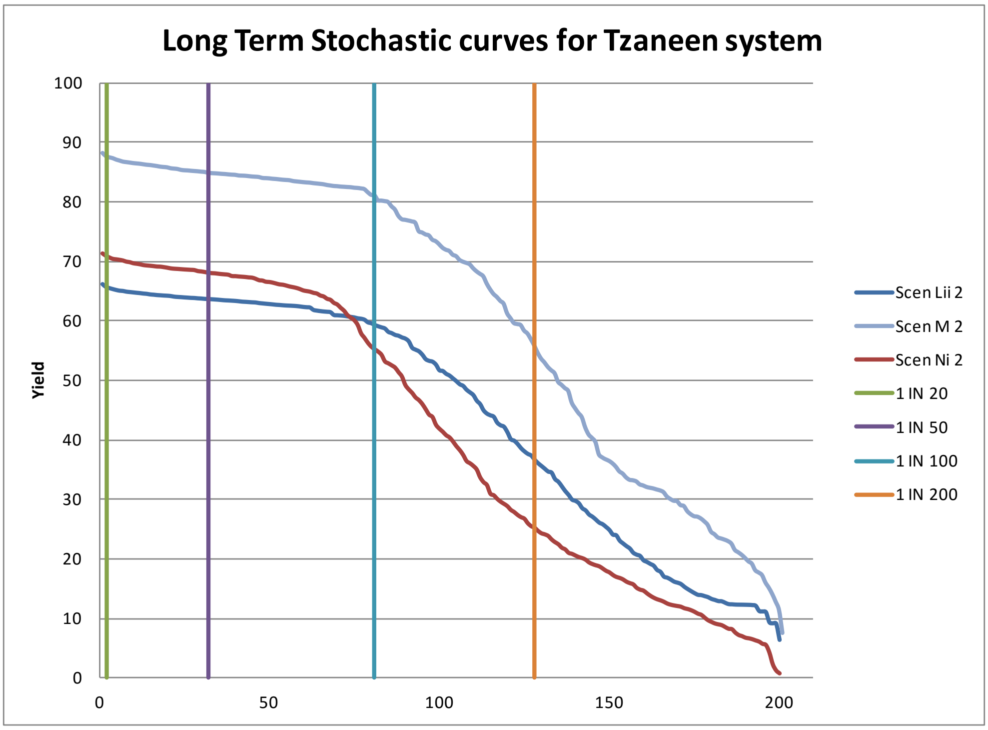


Figure 34: Long-term stochastic curve based on minimum supply

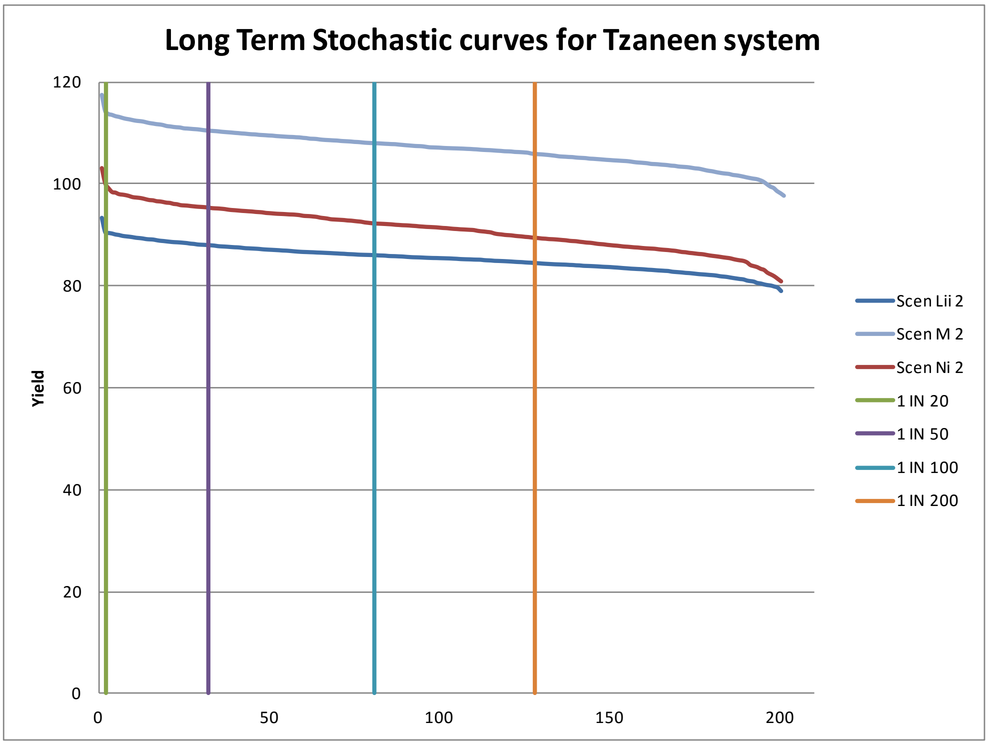


Figure 35: Long-term stochastic curve based on average supply

4.3.2.4 Scenario analyses

From the *Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System* study, many of the analyses were carried out in the traditional manner of determining an HFY by removing all demands from the resource, and determining the resource capability under historical conditions. However, Tzaneen Dam could not be assessed accurately in this manner. This is because many of the users supplied from Tzaneen Dam are situated far downstream in the catchment, and therefore have additional access to incremental run-off occurring between themselves and the Tzaneen Dam. Therefore, it is more beneficial to monitor supply to the users in order to get a picture of the yield capabilities of the total system.

Scenario Lii from the *Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System*: *Yield Analysis Report* (DWS, 2014c) was used as point of departure for the scenario analysis in this study. Table 59 summarises the details and purpose of Scenario Lii. For Scenario Lii, the total average supply was 82.6 million m^3/a to users, 66.4 million m^3/a to irrigators and 16.2 million m^3/a to urban. This equates to 61% supply to irrigators and 97% supply to urban.

Table 59: Scenarios for the Groot Letaba System

Scenario ref.	Details	Purpose of scenario
Lii	Abstractions by users at their specific locations, zero yield removed from Tzaneen Dam.	To determine total system capabilities including incremental run-off between Tzaneen Dam and users, to determine non-firm yield.
Lii 2	Lii with the current abstractions from Ebenezer Dam and support from Ebenezer Dam to Tzaneen Dam.	To determine benefit of Ebenezer support at Tzaneen on user supply.

For Scenario Lii 2, the total average supply was 85.7 million m^3/a to users, 69.3 million m^3/a to irrigators and 16.4 million m^3/a to urban. This equates to 67% supply to irrigators and 99.6% supply to urban. Run control settings in the WRYM were used to define general information on how the system would be analysed for a particular model run. For the yield analysis of the study area, the most important settings are summarised in Table 60.

Table 60: Scenario for the Groot Letaba River System

Scenario (WRPM ref.)	Description
Sc Lii 2	**System analysed:** 10-year period **Stochastic sequences:** 1000 **Reservoir start storage levels:** 50% **Demands:** 2014 demands (with expected growth over the analysis period). (Restrictions are based on dam operating levels and not user priority criteria as per WRPM allocation.)

Numerous irrigation blocks were defined and configured in the WRYM as part of the water use within the irrigation schemes that depend on the Ebenezer, Hans Merensky, Magoebaskloof and Tzaneen dams as water resource. These irrigation blocks are summarised in Table 61.

Table 61: Summary of irrigation from schemes in the Groot Letaba System

Scheme name and source	WRYM block numbers	Irrigated area (km^2)	Irrigation demand
1. Ebenezer	140, 141, 142, 143, 144, 145, 146, 147, 148	19.92	10.26
2. Hans Merensky	38	6.73	4.51
3. Magoebaskloof	32	5.58	4.60
4. Tzaneen	66, 110, 249, 320, 322, 334, 335, 338, 345, 346, 348, 349, 350, 395, 396, 408, 58, 63, 64, 65, 72, 250	122.58	72.70
5. RPF allocation	–		31.33*

*This volume has not been included in the analysis.

4.3.3 Mhlathuze River System

4.3.3.1 Background

The Mhlathuze River System is situated in the KwaZulu-Natal province and supplies water to the various water user sectors in and around Richards Bay and Empangeni. Two principal agricultural activities within the Mhlathuze River System are timber and sugar cane. Diverse mining activities make up a significant part of the urban sector. The government water control area has a scheduled area of 16 612 ha and the total area of crops under irrigation is more or less 15 127 ha of which bananas and citrus over and above sugar cane are also significant components.

Figure 36 illustrates the Mhlathuze River System.

Figure 36: Mhlathuze River System

4.3.3.2 *Water requirements*

Table 62 summarises the irrigation areas and volumes per irrigation region for the different sources of information. Table 63 summarises the irrigation blocks configured in the WRYM and the per the call-for-licences scenario.

Table 62: Irrigation in the Mhlathuze River System from various sources

Area	WARMS	Validation	Verification report (1)	Verification updated (1)	Call for licences
Heatonville (11 800 m^3/ha)	6 271 ha	5 493 ha	5 231 ha 61 724 260 m^3	5 262 ha 62 090 040 m^3	4 610 ha 54 398 800 m^3
Nkwaleni (12 600 m^3/ha)	8 589 ha	6 463 ha	6 102 ha 76 885 200 m^3	6 717 ha 84 630 555 m^3	6 561 ha 82 664 316 m^3
Mfuli (11 800 m^3/ha)	884 ha	895 ha	788 ha 9 298 400 m^3	788 ha 9 297 372 m^3	823 ha 9 705 972 m^3
Lower Mhlathuze (9 000 m^3/ha)	648 ha	651 ha	1 279 ha 11 511000 m^3	1 276 ha 11 485 809 m^3	1 339 ha 12 052 550 m^3
Non-irrigation board members	1 778 ha	1 621 ha	1 736 ha 15 623 349 m^3	815 ha 7 332 058 m^3	2 265 ha 7 624 922 m^3
Emerging farmers (Inkasa)	927 ha	2 068 ha	-	145 ha 1 301 190 m^3	511 ha 10 197 000 m^3
Total	**19 546 ha**	**17 191 ha**	**15 136 ha** **175 042 209 m^3**	**15 002 ha** **176 137 024 m^3**	**16 109 ha** **176 643 560 m^3**

The water requirements information for the existing lawful use (ELU) and new licence applications in the Mhlathuze Catchment among the irrigation, urban and industrial and streamflow reduction activities user sectors are elaborated in this section. Data was obtained from the Water Authorisation and Administration Management System (WARMS), original validation and verification data, updated verification data and the call-for-licences data.

Table 63: WRYM irrigation block summary as per call-for-licences scenario

WRYM block number	Demand channel number	Return flow channel number	Area (km^2)	Volume (m^3/annum)
101	2	3	0.00	0
104	16	17	30.00	180 000
106	27	28	1 771.73	22 323 794
107	30	31	3.13	39 375
108	33	34	383.79	4 835 712
109	38	39	2 023.60	25 497 407
113	50	51	75.56	214 300
114	66	67	616.47	7 274 277
115	69	70	145.00	1 301 190
116	73	74	73.67	869 319
117	75	76	94.13	1 110 708
118	80	81	844.10	9 960 380
119	78	79	598.10	7 057 580
120	103	104	395.60	3 560 435
121	99	100	64.96	434 640

WRYM block number	Demand channel number	Return flow channel number	Area (km^2)	Volume (m^3/annum)
122	113	114	73.00	520 279
123	123	124	8.89	80 000
124	128	129	10.00	81 000
126	241	240	617.39	7 779 111
127	242	243	135.08	1 702 008
128	244	245	1 616.57	20 368 784
129	246	247	206.08	2 431 695
131	250	251	994.32	8 395 475
132	252	253	878.30	2 575 541
133	254	255	1 074.03	3 635 802
140	259	260	1 903.20	22 457 761
141	263	264	1 096.87	12 943 052
142	267	268	9.38	118 125
Total			**15 742.93**	**167 747 750** (1)

[1]A smaller use by Inkasa irrigators of 1 301 190 million m^3/a instead of the planned future 10 197 000 million m^3/a, was included.

The new applicants include those users applying for a WUL for the first time as well as the users applying for more than their ELUs. However, the system will not be in balance if all new applications were approved; therefore, only half of the total volume applied for by historically disadvantaged individual (HDI) users were considered. This was called the objection demand since non-HDI users were likely to object to the full volume application. Table 64 summarises the water requirement of the new applicants.

Table 64: Summary of new irrigation applicants in m^3

Quaternary	HDI	Non-HDI	Objection demand to be included
W12A		230 000	115 000
W12B		40 000	20 000
W12C	578 200	625 000	312 500
W12D	30 000		0
W12E	561 200		0
W12F	255 000	1 621 900	0
W12H	315 000	4 583 015	2 052 500
Total	**1 739 400**	**7 099 915**	**2 500 000**

The irrigation requirements subject to restrictions as configured in the F01 file of the WRPM call-for-licence data set are listed in Table 65. The areas and volumes are at 60% of the initial allocation except for Channel 115, which is intended for RPFs and not subject to restrictions at this time. Users that are not part of an irrigation board are also excluded from the water requirements listed. The urban and industrial water requirements are listed in Table 66.

Table 65: Irrigation water requirements

Irrigation block number	Demand channel number	Return flow channel number	Area (ha)	Volume (m^3/annum)
106	27	28	1 063.00	13.39
107	30	31	1.90	0.02
108	33	34	230.30	2.90
109	38	39	1 214.20	15.30
114	66	67	369.90	4.36
115	*69*	*70*	*511.00*	*1.30*
116	73	74	44.20	0.52
117	75	76	56.50	0.67
118	80	81	506.50	5.98
119	78	79	358.90	4.23
120	103	104	237.40	2.14
123	123	124	5.30	0.05
126	241	240	370.40	4.67
127	242	243	81.00	1.02
128	244	245	969.90	12.22
129	246	247	123.60	1.46
131	250	251	596.60	5.04
140	259	260	1 141.90	13.47
141	263	264	658.12	7.77
142	267	268	5.60	0.07
		Total	**8 546.22**	**96.58**

Table 66: Urban and industrial uses in the Mhlathuze River System from various sources in m^3

Source	WRYM channel no.	Details	Call for licences	ELU	WARMS
W12A	5	Nkandla Urban	268 755	268 755	268 755
Goed	106	Mtonjaneni Rural	525 600	525 600	525 600
Goed	106	KwaHlokohloko Rural	328 500	328 500	328 500
W12E	89	Ngwelazane Urban	2 920 000	1 890 105	2 920 000
W12F	273	Tongaat Hulett	1 888 000	1 888 000	1 888 000
W12F	635	Megawatt (MW) to Ticor	9 490 000 (2)		9 490 000
W12F	635	MW to Mondi Packaging Felixt	3 150 000 (2)		3 150 000
Cubhu	135	Felixton	1 443 883	1 443 883	1 443 883
W12F, Cubhu	636	MW to Esikhaweni	5 475 000 (2)		5 475 000
Cubhu	135	Vulindlela Urban	6 696 000	4 334 297	6 696 000
Nsezi	127	MW to Mondi Kraft Rich Bay	54 750 000 (1)	60 400 000	54 750 000
Nsezi	637	MW to Empangeni Urban	6 570 000 (1)	2 480 000	6 570 000
Nsezi	637	Umhlat Loc Mun, Lake Nsezi	1 768 440	1 768 440	1 768 440
Nsezi	638	MW to Foscor Potable	4 964 000 (2)		4 964 000
Mzin, Nsezi	167	Richards Bay Industrial			7 300 000
Mzin, Nsezi	167	Richards Bay Urban	24 180 000	15 651 627	24 180 000
Mzin, Nsezi	167	MW to City of Mhlathuze for Richards Bay	7 300 000 (1)	7 300 000	7 300 000
Nhla, Nsezi	323 & 146	MW to RBM [9 million m^3 is for smelter (chan. 323), 7.425 million m^3 for Ponds (chan. 146)]	16 425 000 (1)	14 600 000	16 425 000

Source	WRYM channel no.	Details	Call for licences	ELU	WARMS
Mfol, Nhla, Nsezi, Sok	146	RBM Zulti North Ponds	15 575 000	25 000 000	25 000 000
W12H	118	Nseleni Water Treatment Works		1 203 971	1 860 000
		Nkwaleni Processors		26 163	26 163
	301	Ging/Eshowe/Mtunzini	1 200 000	1 200 000	1 200 000
		Dept Public Works		14 980	14 980
		Zululand Diocesan		55 500	55 500
		Zenith and Nieuwenhuys			1 755
		lismore	12 875	26 902	26 902
		Shakaland	9 125	9 125	33 600
		Intaba Ingwe	12 820	120 000	120 000
		Registration Cancelled			6 272 372
		Totals	**164 952 998**	**140 535 848**	**190 054 450**

Note 1: These demands are included in the total volume of 108 124 000 m^3 applied for by Mhlathuze Water and should be included in modelling scenarios from the beginning.

Note 2: These demands are included in the total volume of 108 124 000 m^3 applied for by Mhlathuze Water; however, should only be included in simulations after Thukela pumping is switched on.

The urban and industrial requirements subject to restrictions as configured in the F01 file of the WRPM call-for-licence data set are listed in Table 67 and categorised per user sector. The volumes are at the full initial allocation and not the 90% as in the recommended scenario.

Table 67: Urban and industrial water requirements

Channel number	User	Volume (m^3/annum)	Sector
5	*Nkandla Demand*	*0.27*	*no restriction*
106	Goedetrouw Dam Demands	0.85	Urban
89	Ngwelazane Demand	2.92	
135	Ezikheweni Demand	8.14	
167	Foscor Richards Bay Demand	31.48	
301	Goedetrouw To Eshowe Transfer	1.2	
636	Esikhaweni	5.48	
637	Empangeni	8.34	
273	Ticor Tongaat Etc Demands	1.89	Industry
127	Empangeni Mondi Nsezi Demand	54.75	
323	RBM Smelter Demand	9	
146	RBM Zulti North Ponds Demand	23	
118	Nseleni Demand	0	
635	Ticor, Mondi Felixton	12.64	
638	Foscor Potable	4.96	
Sub-total: Existing users		**164.65**	**excl. Nkandla**
649	New	1.14	Urban
650	New	0.31	
651	New	0.63	
652	New	13.99	
653	New	3.29	
654	New	0.05	

Channel number	User	Volume (m^3/annum)	Sector
655	New	0.08	
656	New	6.44	
657	New	0.01	
Sub-Total: New applicants		**25.94**	
Total		**190.59**	
Sub-total: Urban		**84.35**	
Sub-total: Industry		**106.24**	

Table 68 summarises the SFR activities within the Mhlathuze River System and Table 69 lists the new applicants.

Table 68: SFR summary table in m^3

Quaternary	WARMS	Validation	Aerial photographs MWAAS (1)	Verification	Call for licences
W12A	17 927	17 952	17 308	13 993	14 190
W12B	4 908	4 858	5 077	2 893	3 847
W12C	9 475	9 098	13 314	6 404	6 950
W12D	1 352	1 352	919	181	643
W12E	5	5	53	0	0
W12F	2 685	2 634	3 457	2 116	2 504
W12G	0	0	5	0	0
W12H	12 495	12 818	12 935	7 850	11 031
W12J	12 192	12 388	14 642	10 118	10 837
Other	87	87		17	
Total	**61 127**	**61 192**	**67 711**	**43 571**	**50 001**

Table 69: New applicants SFR sector in m^3

Quaternary	HDI	Level 3	Non-HDI	Total
W12A	29	271	1 014	1 314
W12B	80		536	616
W12C	125	36	3 699	3 861
W12D			10	10
W12E				0
W12F	213	35	718	966
W12G	6		275	281
W12H	113	209	1 211	1 533
W12J		2	96	98
Total	**566**	**553**	**7 560**	**8 679**

The average EWR over a historical period is presented in Table 70. The EWRs are configured in the WRYM in such a way that it has priority over the other demands in the system.

The Mhlathuze Catchment is renowned for its large sugar cane production and is located in a region with high rainfall compared to the other study areas. The most common crops (with areas and volumes) cultivated within the irrigation schemes in the Mhlathuze River System are listed in Table 71 and Table 72 for 100% and 60% of the irrigation allocation respectively. The areas and volumes listed are specifically those that have been configured in the WRPM and WIM for analysis purposes.

Table 70: Summary of simulated EWRs

EWR	Channel no.	Position	Average EWR over historical period (million m^3/a)
IFR 1	148	W12A Outlet	16.97
IFR 2	149	Downstream Goedertrouw Outlet of W12B	41.07
IFR 4	151	W12C Outlet	7.06
IFR 5	152	In W12D downstream of Mhlathuze–Mfuli Confluence	32.61
IFR 6	171	W12D Outlet	31.81
IFR 7	154	W12E Outlet, not including Mhlathuzana River Contribution	32.19
IFR 8	155	Upstream of Mhlathuze-Nsezi Confluence	37.19
IFR 9	156	W12G Outlet	3.40
IFR 10	157	W12H Outlet	10.22
EFR 1	158	Mhlathuze Mouth	10.85
EFR 2	159	W12J2 Mouth	0.76

IFR – Instream flow requirement

Table 71: Irrigation in the Mhlathuze River System at 100% allocation

Crops	Area (hectares)	Average water use (m^3/ha)	Volume (million m^3)
Maize	–	–	–
Soya beans	–	–	–
Dry beans	–	–	–
Industrial tomatoes	–	–	–
Fresh tomatoes	–	–	–
Potatoes	–	–	–
Summer vegetables	222	2 411	0.53
Winter vegetables	563	1 578	0.89
Wheat	–	–	–
Lucerne	–	–	–
Sugar cane	10 219	12 392	126.6
Bananas	313	9 981	3.13
Grapes – fresh	–	–	–
Grapes – wine	–	–	–
Grapes – dry	–	–	–
Macadamias	–	–	–
Citrus – oranges	–	–	–
Citrus – grapefruit	2 586	11 185	28.9
Avocados	–	–	–
Litchis	–	–	–
Deciduous fruit	–	–	–
Palm dates	–	–	–
Mangoes	–	–	–
Total	**13 903**		**160.11**

Two approaches were followed in terms of the irrigation areas and volumes to be applied for the analyses. These were identified as two scenarios. Even though it had been recommended from the call-for-licences study that the original allocation to the irrigation sector be cut with 40%, the original 100% allocation will also be used as a scenario in the analyses in order to test the alternate user priority classification.

Table 72: Irrigation in the Mhlathuze River System at 60% allocation

Crops	Area (hectares)	Average Water Use (m^3/ha)	Volume (million m^3)
Maize	–	–	–
Soya beans	–	–	–
Dry beans	–	–	–
Industrial tomatoes	–	–	–
Fresh tomatoes	–	–	–
Potatoes	–	–	–
Summer vegetables	136	2 366	0.32
Winter vegetables	346	1 549	0.54
Wheat	–	–	–
Lucerne	–	–	–
Sugar cane	6 282	12 161	76.4
Bananas	193	9 795	1.89
Grapes – fresh	–	–	–
Grapes – wine	–	–	–
Grapes – dry	–	–	–
Macadamias	–	–	–
Citrus – oranges	–	–	–
Citrus – grapefruit	1 589	10 977	17.5
Avocados	–	–	–
Litchis	–	–	–
Deciduous fruit	–	–	–
Palm dates	–	–	–
Mangoes	–	–	–
Total	**8 546**		**96.58**

Table 73 lists and categorises the different irrigation crops cultivated in the Mhlathuze River System according to type. Up to 97.5% of the crops are of a permanent type and only 2.5% are temporary. This emphasises the importance of developing restriction rules that will not only prevent the water resource from failing, but also the permanent crops from reaching wilting point.

Table 73: Crop type distribution (% Mhlathuze)

Crop	Percentage (%)	Type	Percentage (%)
Summer vegetables	1.6%	Temporary	5.6%
Winter vegetables	4.0%		
Citrus (grapefruit)	18.6%	Permanent	94.4%
Bananas	2.3%		
Irrigated sugar cane	73.5%		

4.3.3.3 Scenario development

Both the ELU and requirements from the call-for-licences scenarios were used for analyses. For the ELU scenario, significant adjustments had to be made to the water requirements to comply with the assurance of supply criteria defined for all abstractions. Within this scenario, two irrigation scenarios were considered: one with a variable water requirement; the other with a constant water requirement. In addition to these, a scenario including transfers from the Thukela and a scenario without transfers were also considered. Table 74 summarises the results from these analyses.

The results show that the ELUs in the Mhlathuze River System are significantly higher than the volume of water available from the system; therefore, reductions in the water-use entitlements are necessary.

When applying the constant irrigation water requirement scenario, the irrigation and streamflow reduction activity sectors had to be reduced to 70% of the ELU. The urban and industrial sectors, which benefit from the Thukela–Mhlathuze Transfer Scheme, could be increased to 105% of the ELU.

If the alternative variable irrigation water requirement scenario is applied, the irrigation and streamflow reduction activity sectors had to be adjusted to 75% of the ELU. The urban and industrial sectors, which benefit from the Thukela–Mhlathuze Transfer Scheme, could be increased to 110% of the ELU.

It can therefore be concluded that the variable irrigation water requirement scenario has a slight advantage over the constant irrigation water requirement pattern. In applying the equal proportion adjustment method, it is only the streamflow reduction sector that will have to be reduced below the current water use. In order to avoid a disruption to the economic activities of this sector, an exchange of water-use entitlement would be necessary. The results of Scenario C3 provide a possible entitlement exchange option where the irrigation sector entitlement is adjusted by 65% of the ELU while the SFR is maintained at the current water use, and the urban and industrial sectors receive their full ELU entitlements.

Observations from the scenario result showed that by accepting minor adjustments to the assurance of supply criteria, it will be possible to increase the water-use entitlements above the initial use.

By applying an alternative assurance of supply criterion to the industrial sector, the adjustment factor to the entitlement of the irrigation sector for Scenario C3 could be 70%, which is an increase of 5% compared to the result for Scenario C2 in Table 74.

Based on the findings from the study, it was recommended that additional sensitivity analysis be carried out to evaluate the effect that alternative assurance of supply criteria could have on the allocation balance (resulting water-use entitlements). The analysis results indicated that minor changes in the criteria could have a substantial effect on the results and therefore warrant further investigations.

It was agreed that the following approach will be used to carry out the simulations. The purpose of the simulations is to use the most up-to-date information on ELU and new applications, along with the new version of the WRYM to determine a system balance. Table 75 presents the scenarios that were analysed.

Table 74: Mhlathuze River System water-use entitlement adjustments and associated water requirement volumes

Scenario	Water-use entitlement adjustment factor (percentage of ELU)			Water requirements					Comments
	Irrigation sector	Urban/ industrial sectors	Streamflow reduction activities	Irrigation sector		Urban/ industrial sectors	Streamflow reduction activities	Total	
				Maximum	Average				
Units:	%			Million m³/annum					–
A1	70	70	70	123.3 (211%)	123.3 (211%)	98.2 (115%)	31.6 (46%)	253.1 (119%)	No transfer from Thukela River (first round of adjustments)
A2	75	75	75	132.1 (226%)	99.8 (171%)	105.2 (123%)	33.9 (49%)	271.2 (127%)	
A3	No adjustments needed to the 2008 development level water requirements			58.5	58.5	85.7	68.7	212.9	
A4	72	72	100	126.79	95.62	101.02	45.2	273.01	
B1	70	105	70	123.3 (211%)	123.3 (211%)	147.3 (172%)	31.6 (46%)	302.2 (142%)	Full transfer from Thukela River (second round of adjustments)
B2	75	110	75	132.1 (226%)	99.8 (171%)	154.3 (180%)	33.9 (49%)	320.3 (150%)	
C2	65	100 ELU	100 current	114.5 (196%)	86.3 (196%)	140.3 (164%)	68.7 (100%)	323.5 (152%)	Full transfer from Thukela River (only irrigation adjusted)

Note: The values in brackets indicate the percentages of the adjusted volumes relative to the 2008 development year water use.

Table 75: Scenario descriptions

Scenario	Thukela pumping	Sector	Description
		Irrigation	All ELUs in (167 747 750 million m^3 as per Table 63) and only irrigation boards scaled downwards to obtain a balance.
1A	No	Objection	Objection demand (2 500 000 million m^3 as per Table 64).
		SFR	All ELUs in (50 001 ha as per Table 68) and scaled downwards to obtain a balance.
		Urban-industrial	All ELUs used for initial simulations (141 839 178 million m^3) and scaled downwards to obtain a balance.
		Irrigation	All ELUs in (167 747 750 million m^3 as per Table 63) and only irrigation boards scaled downwards to obtain a balance.
1B	No	Objection	Objection demand (2 500 000 million m^3 as per Table 64).
		SFR	All ELUs in (50 001 ha as per Table 68) and not modified.
		Urban-Industrial	All ELUs used for initial simulations (141 839 178 million m^3) and scaled downwards to obtain a balance.
		Irrigation	Kept at level determined in Scenario 1B.
2B	Yes	Objection	Objection demand (2 500 000 million m^3 as per Table 64).
		SFR	All ELUs in (50 001 ha as per Table 68).
		Urban-Industrial	Additional MW demands referred to in Note 2 of Table 66 included and all back to 100% (90% to be ok!).
		Irrigation	All ELUs in (167 747 750 million m^3 as per Table 63) and new applicants (1 739 400 million m^3 as per Table 64) only irrigation boards scaled downwards to obtain a balance.
3B	No	Objection	Objection demand (2 500 000 million m^3 as per Table 64).
		SFR	All ELUs in (50 001 ha as per Table 68) and new HDIs and Level 3 applicants (1119 ha as per Table 69). No scaling to take place.
		Urban-Industrial	All ELU (141 839 178 million m^3) and new applicants (25 945 920 million m^3). Both ELUs and new applicants scaled downwards to obtain a balance.
4B	Yes	Irrigation	Kept at level determined in Scenario 3B.
		Objection	Objection demand (2 500 000 million m^3 as per Table 64).
		SFR	All ELUs in (50 001 ha as per Table 68) and new HDIs and Level 3 applicants (1119 ha as per Table 69).
		Urban-Industrial	Additional MW demands referred to in Note 2 of Table 66 included.
5	No		Repeat of Scenario 1B with EWR switched off.

Additional scenarios were requested after submission of the initial results and are described below:

- Scenario 3C: Scenario 3B with irrigation boards at 60% to determine what percentage of urban/ industrial can be met.
- Scenario 4C: Scenario 4B with irrigation boards at 60% to determine what percentage of urban/ industrial can be met.
- Scenario 4D: Scenario 4B with irrigation boards at 65% to determine what percentage of urban/ industrial can be met.

The following assumptions were used for all the simulations:

- 453 stochastic sequences were simulated.
- Supply criteria for urban, industrial and irrigation demands as presented in Table 76 and forestry are supplied by the available rainfall and uses all water obtainable.
- 10% of irrigation return flows are entered back into the system.
- Latest available scaled EWRs from Mhlathuze Water Availability Assessment Study (MWAAS) were in place in all scenarios except Scenario 5.

It should be kept in mind that the method applied to adjust the water-use entitlements in the Mhlathuze River System accounted for the development history of the transfer scheme from the Thukela River. When the transfer scheme was implemented, only the urban and industrial users contributed financially to the augmentation option – the irrigation sector did not partake in the financing of the scheme (Memo, 1997; Agreement, 1997).

An additional task was included in the *Mhlathuze Catchment – Modelling Support for Licensing Scenarios Study* where the WRPM configuration that was developed, was initially based on the WRYM configuration and used the updated hydrology developed in the MWAAS (DWA, 2012). Subsequent to the initial configuration of the WRPM based on the MWAAS WRYM configuration, additional modifications were made to the WRYM configuration in order to simulate the system for the call-for-licences scenario. These changes were incorporated in the WRPM such that the configuration closely resembled that of the state of the catchment at a specific time and in future; it is referred to as Scenario 4C in the *Modelling Support for Licensing Scenarios Study*.

This was the recommended scenario from the study where a system balance of 90% to the urban and industrial sector and 60% to the irrigation sector was obtained using scaled EWRs. The user priorities at the various assurance of supply levels, as configured for the Base Scenario in the `*.fm` file, are given in Table 77 as percentages. Table 78 list the user priorities as volumes in million cubic metres per annum.

Table 76: Base Scenario user priority classification (%)

Water-use sector	% demand at indicated risk of failure				
	1 in 200 years	1 in 100 years	1 in 50 years	1 in 20 years	1 in 4 years
	0.5%	1%	2%	5%	25%
Irrigation			50%		50%
Urban	30%	30%		30%	10%
Industrial	70%	20%		10%	

Table 77: Base Scenario user priority classification (million m³/annum) (100%–60% scenario)

Water-use sector	Volume demand at indicated risk of failure (million m³/annum)					
	1 in 200 years	1 in 100 years	1 in 50 years	1 in 20 years	1 in 4 years	Total
	0.5%	1%	2%	5%	25%	
Irrigation			48.29		48.29	96.58
Urban	25.31	25.31		25.31	8.44	84.35
Industrial	74.37	21.25		10.62		106.24
Total	**99.67**	**46.55**	**48.29**	**35.93**	**56.73**	**287.17**

Figure 37 plots the user water requirements at different risk levels on the long-term stochastic curve for the 100%–60% scenario. With this scenario, it is probable that there will be a violation of the 1-in-4-year user priority risk criteria where there is an imbalance between the system yield and the water requirement at the specific level of assurance of supply.

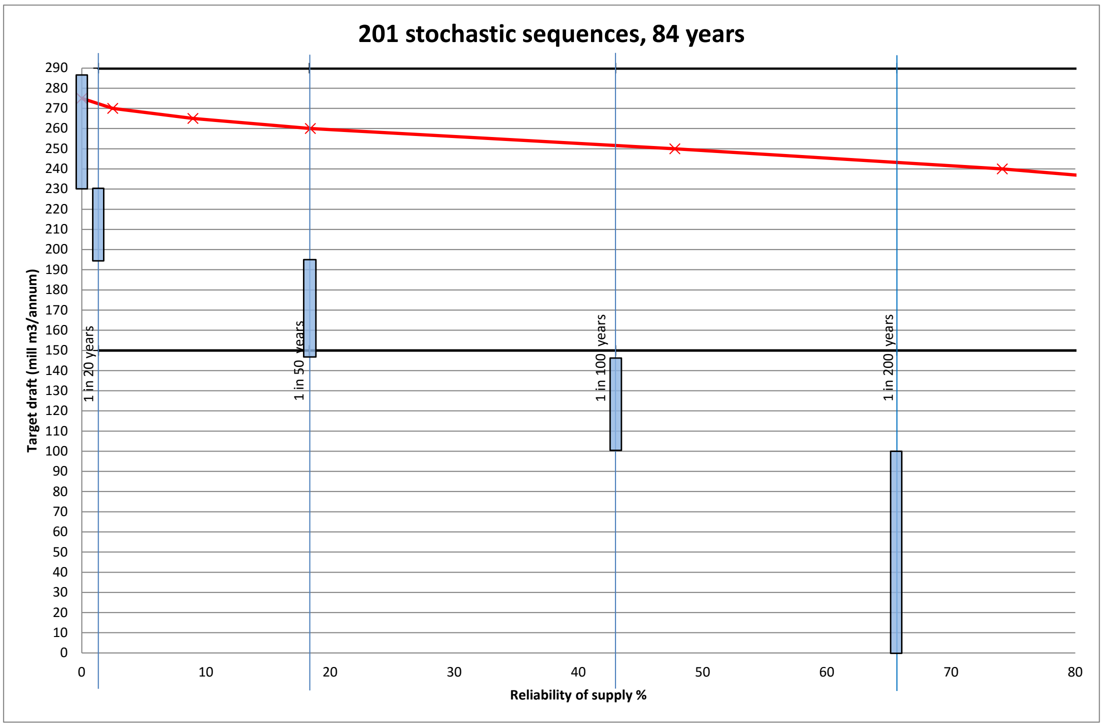


Figure 37: Long-term stochastic curve with 100%–60% scenario

For the 90%–60% scenario, however, the system seems to be in balance and the total water requirement of 268 million m³/annum can be supplied as illustrated in Figure 38, where the total water requirement (blue bar) remains below the firm yield line (red).

Table 78: Base Scenario user priority classification (million m³/annum) (90%–60% scenario)

Water-use sector	Volume demand at indicated risk of failure (million m³/annum)					
	1 in 200 years	1 in 100 years	1 in 50 years	1 in 20 years	1 in 4 years	Total
	0.5%	1%	2%	5%	25%	
Irrigation			48.29		48.29	96.58
Urban	22.77	22.77		22.77	7.59	75.915
Industrial	66.93	19.12		9.56		95.616
Total	**89.71**	**41.90**	**48.29**	**32.34**	**55.88**	**268.11**

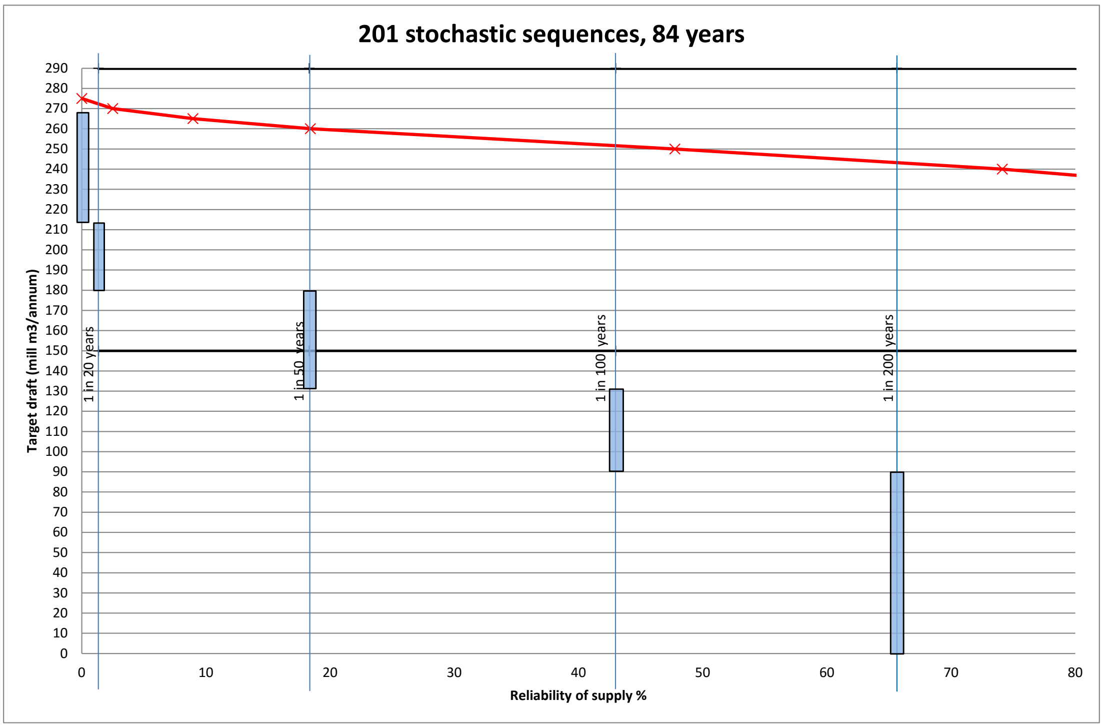


Figure 38: Long-term stochastic curve with 90%–60% scenario

It is important however to look at the shorter term for planning and drought restrictions analyses. Therefore, the 90%–60% scenario was also plotted on the short-term stochastic curve in Figure 39 with a 60% starting storage for the resource system at the start of the planning year. The stakeholders were not satisfied with the 90%–60% option, and requested that further work be undertaken to see how their assurances would be impacted if a demand of 90% for the urban-industrial and 70% for the irrigation sector was used. The 90%–70% split result showed that, for the Heatonville demand, the users only got 30% of their water at a 1-in-50-year assurance (98%). The industry only got 80% at a 1-in-100-year assurance. A sensitivity analysis consisting of an iterative process can be undertaken to find the best user priority classification without having to cut back more on the total water requirement.

A Government Notice (No. 38599) by the DWS was published on 25 March 2015 stating the final allocation schedule for the Mhlathuze River System. Although there are differences between the volumes specified in the Government Notice and that of the *Modelling Support for the Licensing Report*, it was decided to use the volumes currently configured in the WRPM, as indicated earlier in this section. Table 79 summarises the final scenario descriptions adopted to be analysed in the Mhlathuze Water Supply System.

Table 79: Final reference adopted for scenarios to be analysed in the Mhlathuze System

<table>
<tr><th>Scenario</th><th>Description</th><th colspan="2">User priority classification</th><th></th><th>Scenario</th></tr>
<tr><td rowspan="2">Scenario 1 (100%–100%)</td><td rowspan="2">Full urban and irrigation allocation as system water requirements</td><td rowspan="6">Original</td><td rowspan="6">Alternative A</td><td rowspan="6">⇨</td><td>Sc 1</td></tr>
<tr><td>Sc 1a</td></tr>
<tr><td rowspan="2">Scenario 2 (100%–60%)</td><td rowspan="2">100% of urban and 60% of irrigation allocation as system requirements</td><td>Sc 2</td></tr>
<tr><td>Sc 2a</td></tr>
<tr><td rowspan="2">Scenario 3 (90%–60%)</td><td rowspan="2">90% of urban and 60% of irrigation allocation as system water requirements</td><td>Sc 3</td></tr>
<tr><td>Sc 3a</td></tr>
</table>

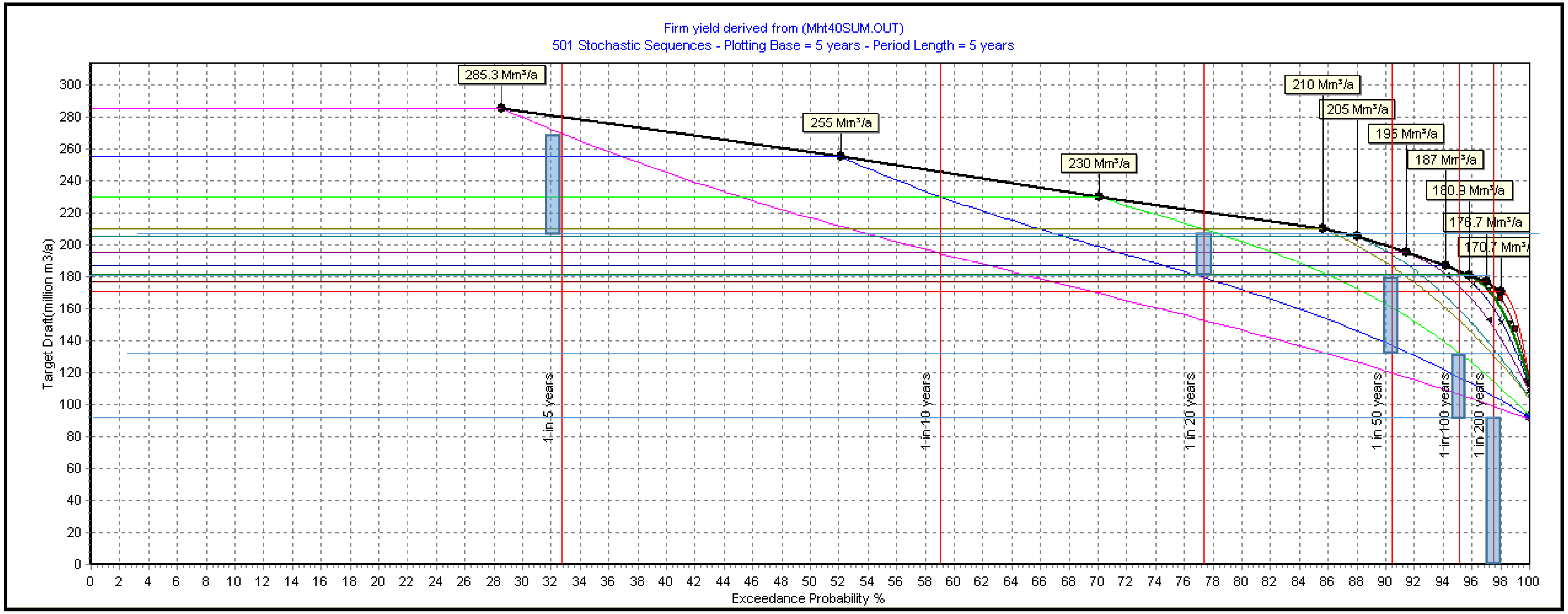


Figure 39: Short-term stochastic curve at 60% starting storage with 90%–60% scenario

4.3.3.4 Scenario analyses

The Base Scenario adopted for the analyses in this research study was the same as the scenario (4C) that was developed for the *Modelling Support for Licensing Scenarios Study*. This was the recommended scenario from the study where a system balance of 90% to the urban and industrial sector and 60% to the irrigation sector was obtained using scaled EWRs. The volume of demands imposed on the Mhlathuze System was that of the 2008 development level. In order to assist with the decision on alternative scenarios in the sensitivity analyses, a scenario where 100% of the urban and industrial sector as well as 100% of the irrigation sector demand can be supplied was analysed as base scenario. The scenario analyses are undertaken for a period of 10 years and takes growth into calculation for this period. Alternative scenarios include 100% supply to the urban and industrial sectors and 100% supply to the irrigation sector as well as alternative user priority classification. These scenarios are summarised in Table 80.

The Mhlathuze River System consists of three sub-systems, namely, the Richards Bay sub-system consisting of the Lake Sokhulu and Lake Nhlabane as resources that mainly supply the urban and industrial sector. The Mhlathuze sub-system consists of the Goedertrouw Dam with a full storage capacity of 301 million m^3 as well as Lake Nsezi, Lake Chubu and Lake Mzingazi. The Tugela sub-system is the average annual transfer from the Tugela River to the Mhlathuze River System in the order of 1.2 m^3/s.

Table 80: Scenarios for the Mhlathuze River System

Scenario (WRPM reference)	Description
Scenario 1 (**Base Scenario)**	**Base scenario: Projection analysis used to determine current and future assurance of supply violations, as well as storage projection plots and flow projection plots.** • **User priority classification criteria:** original as per call-for-licence scenario. • **Percentage of allocation supplied:** 100% urban, 100% irrigation. • **System analysed:** 10-year period. • **Reservoir start storage levels:** Full. • **Demands:** Latest updated 2008 demands (with expected growth over the analysis period).
Scenario 2	**Scenario 2: To determine the effect of a reduced allocation to the irrigation sector. Based on the Base Scenario with the following changes:** • **Percentage of allocation supplied:** 100% urban, 60% irrigation.
Scenario 3	**Scenario 3: To determine the effect of a reduced allocation to the irrigation sector. Based on the Base Scenario with the following changes:** • **Percentage of allocation supplied:** 90% urban, 60% irrigation.

Table 81 summarises the percentages at which the water demand is supplied to the various user sectors at different assurance of supply levels for each of the options of user priority classification criteria applied.

Table 81: Percentages of user sectors prioritised at different assurances

User Sector	Percentage of the water demand to be supplied									
	High (99.5% assurance) 1 in 200 year		Medium high (99% assurance) 1 in 100 year		Medium (98% assurance) 1 in 50 year		Medium low (95% assurance) 1 in 20 year		Low (75% assurance in 1 in 4 year)	
User Priority	**Orig.[1]**	**Alter[2]**	**Orig.[1]**	**Alter[2]**	**Orig.[1]**	**Alter[2]**	**Orig.[1]**	**Alter[2]**	**Orig.[1]**	**Alter[2]**
Irrigation	0	0	0	0	50	75	0	15	50	10
Urban			←		**Unchanged**		→			
Industrial			←		**Unchanged**		→			

[1] Original User Priority; [2] Alternative User Priority

4.4 Farm Producer Economic Scenarios

The scenarios address water assurance on a regional level. Farm gate level output is provided in the different project/catchments by the water supply curtailment modelling system, which includes the WIM, and subsequently by the farm producer economic model. For the farm producer model, the demographics of the producers and the crop mix in the different river catchments will eventually have an impact on their ability to recover after a period of restriction.

Table 82 lists the crop mix derived from different catchments for a standard farm. Farming enterprise groups were defined by land area cultivated and grouped into small-, medium- and large-scale farm size units. Although the water use differs in the project/catchments (refer to Section 3: Study Area), the farm size units representing economic units, as presented in Table 83, are used as proxy for all case studies. The two economic scenarios are about reduction in managerial compensation of the small-scale farmer as well as on the sensitivity of the return on capital when the real capital yield changes.

Managerial compensation refers to the salary per annum that the farmer either pays himself for acting as the farm manager or that he pay the farm manager. When the representative setups for an economic unit for the different farm unit sizes were developed, it was decided that a small-scale farmer would be paid 30% less than large- or medium-scale farmers. This therefore provided a tool for determining the sensitivity of the remuneration relating to the profit/loss of the farmer.

The return on capital also acts as a scenario to investigate the changes of the real interest rate on the long-term capital stock such as farm implements and buildings as well as land with irrigation rights.

Table 82: Crop mix derived from different catchments for a standard farm

		Catchment (ha)		
Life Cycle	**Crops**	**Orange–Great Fish River**	**Groot Letaba**	**Mhlathuze**
Short term	Maize	27	–	0
	Soya beans	–	–	0
	Dry beans	–	–	0
	Industrial tomatoes	–	–	0
	Fresh tomatoes	–	–	0
	Potatoes	6	–	0
	Summer vegetables	9	7.0	2
	Winter vegetables	9	6.0	5
	Wheat	–	–	0
Medium term	Lucerne	246	–	0
	Sugar cane	–	–	88
	Bananas	–	5.0	3
Long term	Grapes – fresh	–	–	0
	Grapes – wine	–	–	0
	Grapes – dry	–	–	0
	Macadamias	–	1.0	0
	Citrus – oranges	3	45.0	0
	Citrus – grapefruit	–	16.0	22
	Avocados	–	23.0	0
	Litchis	–	4.0	0
	Deciduous fruit	–	–	0
	Palm dates	–	–	0
	Mangoes	–	12.0	0
	Total	**300**	**119**	**120**

Table 83: Economical farm size unit for the three case studies (Conningarth, 2017)

		Economical farm size unit (ha)		
Life cycle	**Crops**	**Large scale**	**Medium scale**	**Small scale**
Short term	Maize	250	150	35
	Soya beans	150	100	25
	Dry beans	150	100	25
	Industrial tomatoes	50	25	3
	Fresh tomatoes	50	25	3
	Potatoes	150	80	10
	Summer vegetables	50	30	6
	Winter vegetables	50	30	6
	Wheat	170	110	40
Medium term	Lucerne	60	30	20
	Sugar cane	180	120	35
	Bananas	80	40	3
Long term	Grapes – fresh	60	22	8
	Grapes – wine	40	28	10
	Grapes – dry	40	28	10
	Macadamias	25	12	6
	Citrus – oranges	80	40	15
	Citrus – grapefruit	80	40	15
	Avocados	80	40	15
	Litchis	40	25	12
	Deciduous fruit	80	40	12
	Palm dates	250	100	15
	Mangoes	80	40	15

5 TESTING OF METHODOLOGY

5.1 Objective

The objective of the ASM is to determine the optimal user priority criteria for input to the WRPM by undertaking sensitivity analyses with various scenarios. It is a new decision support tool for determining the optimal assurance of supply requirements. The irrigation curtailment data in the output files of the WRPM is incorporated in the WIM to determine the economic impact of a reduction in water supply to the crops irrigated in a water supply system.

5.2 Strategy

A function was written in Excel™ Visual Basic to link the 1000 simulated system curtailment factors as obtainable from the `sys.out` output file from the WRPM and write the factors directly to the WIM_Socio Economics Excel™ spreadsheet. This required an iterative process due to the number of simulated sequences.

The value of the loss in an economic indicator due to a reduction in volume of water supply is created in the WIM and repeated a 1000 times by means of a loop in Excel™ Visual Basic script. The sheets created for loss in GDP, loss in employment, and loss in household income are WIM_Result_A, WIM_Result_B and WIM_Result_C, respectively. These are created in the ASM shown in Figure 40.

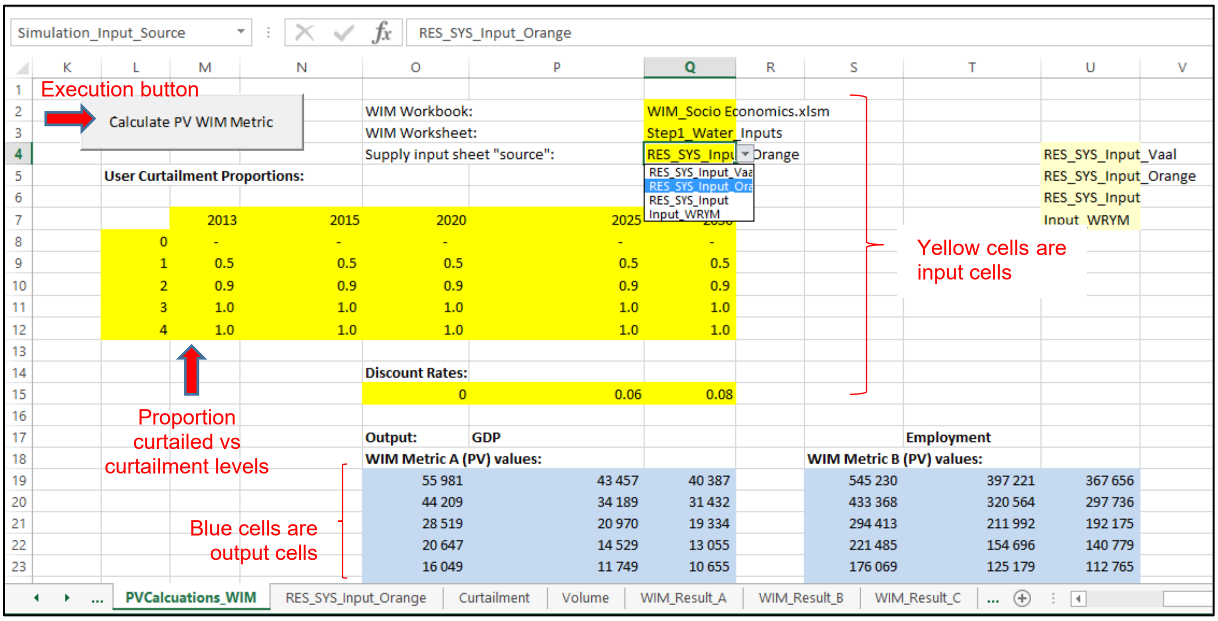


Figure 40: Interface of the ASM

The user curtailment proportions in Figure 40 are for the irrigation sector only and the main input to change in order to find the optimum user allocation for the irrigation sector. The input is cumulative based on the user priority classification. See example in Table 84.

Table 84: User curtailment proportion as input to model

Levels of curtailment	Level 1: 1/20 years (95%)	Level 2: 1/100 years (99%)	Level 3: 1/200 years (99.5%)
Proportion of demand	0.5	0.4	0.1
Cumulative	0.5	0.9	1.0

If the water resource analysis is undertaken in the WRYM, the option `Input_WRYM` should be selected from the dropdown list on the input sheet PVCalculations_WIM (see Figure 40). On the Input_WRYM sheet, the location of the `plt.out` and `dem.out` files must be indicated as well as the various channel numbers and irrigation blocks as configured in the WRYM. Once all the required information has been entered into the Input_WRYM sheet, the execution button on sheet PVCalculations_WIM is clicked. The user curtailment proportions are 1.0 for all levels since this calculation is based on the difference between demand and supply and not the allocation procedure.

Demand and supply results for each of the channels listed for 1000 sequences for the selected analysis period are written to individual channel sheets. Additionally, Annual Total Supply, Annual Total Demand and Annual Proportion sheets are created. The annual proportion is the difference in proportion between the total supply and demand of the system (inclusive of all channels and irrigation blocks). Values from the Annual Proportion sheet are then incorporated to the WIM_Socio Economics spreadsheet from where the same procedure is followed in creating the WIM_Result_A, WIM_Result_B and WIM_Result_C sheets.

5.3 Deliverables

Scenario 1, developed for the Orange River System, was used as example for testing the methodology. The scenario entails a constant development level at the year 2016 with no growth in demand on the system and the original user priority classification as applied in the AOA of the Orange River System.

The WRPM analysis entails simulating 1000 probable levels of curtailment for each year of the analysis period, which can be summarised per percentile probability; these are illustrated in a box-and-whisker plot. The results for Scenario 1 indicated that no system curtailments were required in the year 2016. For the remainder of the analysis period, however, system curtailments were required each year. There was a 5% probability that the level of curtailment would be at 1.239 or more in 2017.

Table 85 lists the annual system curtailments at various exceedance probabilities for Scenario 1 as a result of the analyses undertaken for the Orange River System. The probability distributions of the various curtailment levels for all 1000 simulated sequences are summarised per selected list of percentiles. These probabilities are illustrated graphically in Figure 41, and the levels of curtailment for the 5% probability distribution are indicated on the graph.

This level of curtailment is applicable to the system as a whole and based on the defined risk of curtailment/assurance of supply criteria. Table 86 shows that the proportion of curtailment of 1.239 on the system would entail a complete curtailment of Level 1 and subsequently 50% of the supply to the irrigation sector. In addition to this, a proportion of 0.239 of Level 2, where water is supplied at an assurance of 99%), is curtailed. This means that an additional 0.239 × 40% = 9.56% of supply to the irrigation sector will be curtailed.

Table 85: Annual curtailment levels for Orange River System (Scenario 1)

Percentile	Level of curtailment									
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
0%	0.000	2.339	2.908	2.908	2.561	2.049	2.225	2.347	2.243	2.073
0.5%	0.000	2.068	2.099	2.038	1.567	1.648	2.004	1.601	1.599	1.632
1%	0.000	2.016	1.813	1.771	1.196	1.240	1.621	1.388	1.379	1.508
5%	**0.000**	**1.239**	**1.091**	**0.736**	**0.107**	**0.174**	**0.912**	**0.699**	**0.735**	**0.899**
25%	0.000	0.086	0.000	0.000	0.000	0.000	0.017	0.000	0.075	0.080
50%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
75%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99.5%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

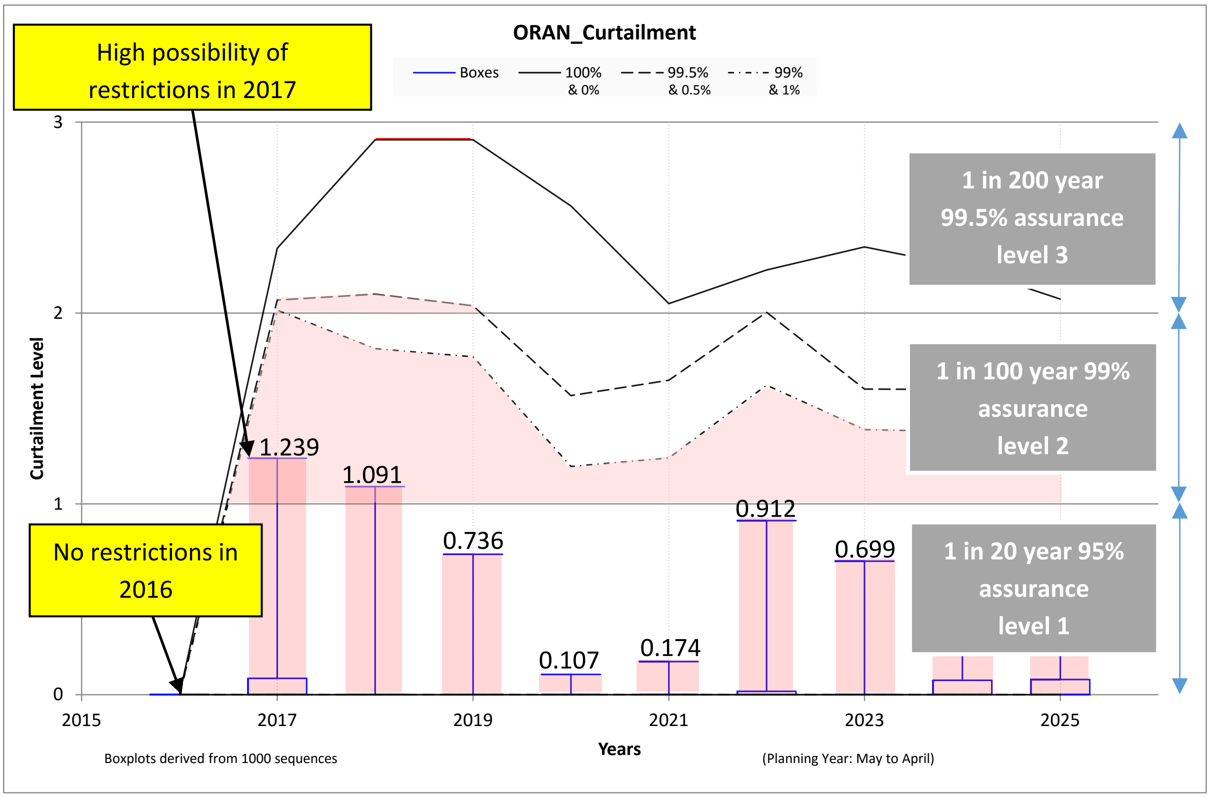


Figure 41: Curtailment plot for Orange River System (Scenario 1)

Table 86: Orange River System irrigation curtailment proportions (Scenario 1)

Levels of curtailment	1/20 years (95%)	1/100 years (99%)	1/200 years (99.5%)	Total
Proportion of demand	0.5	0.4	0.1	1
Volume m³	1 046.5	837.2	209.3	2 093
Level of curtailment	1	2	3	1
Proportion of level curtailed	1	0.239	0	1

Table 87 shows the corresponding curtailments for the irrigation sector at the various exceedance probabilities for Scenario 1 based on the allocation in Table 86 and the total irrigation demand.

Table 88 lists the volume of water supply to the irrigation sector that needs to be curtailed so that system failure does not occur. This curtailed volume was then incorporated into the WIM to establish the economic impact on the irrigation sector as a result of these curtailments.

Table 87: Orange River System irrigation curtailment (Scenario 1)

Percentile	Level of curtailment for the irrigation sector									
	Average	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
0%	0.917	0	0.934	0.991	0.991	0.956	0.905	0.923	0.935	0.924	0.907
0.5%	0.750	0	0.907	0.910	0.904	0.727	0.759	0.900	0.740	0.740	0.753
1%	0.657	0	0.902	0.825	0.808	0.578	0.596	0.748	0.655	0.652	0.703
5%	**0.330**	**0**	**0.596**	**0.536**	**0.368**	**0.054**	**0.087**	**0.456**	**0.350**	**0.368**	**0.450**
25%	0.013	0	0.043	0.000	0.000	0.000	0.000	0.009	0.000	0.038	0.040
50%	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
75%	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95%	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99%	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99.5%	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100%	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 88: Orange River System irrigation volume curtailed (Scenario 1)

Percentile	Volume water supply curtailed million m³									
	Average	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
0%	1918	0	1955	2 074	2 074	2001	1 894	1931	1956	1935	1 899
0.5%	1 570	0	1 898	1904	1 892	1 521	1 589	1 885	1 550	1 548	1 576
1%	1 376	0	1 887	1 727	1 692	1 211	1 247	1 566	1 371	1 364	1 472
5%	**690**	**0**	**1 247**	**1 123**	**770**	**112**	**182**	**954**	**732**	**769**	**941**
25%	27	0	90	0	0	0	0	18	0	78	84
50%	0	0	0	0	0	0	0	0	0	0	0
75%	0	0	0	0	0	0	0	0	0	0	0
95%	0	0	0	0	0	0	0	0	0	0	0
99%	0	0	0	0	0	0	0	0	0	0	0
99.5%	0	0	0	0	0	0	0	0	0	0	0
100%	0	0	0	0	0	0	0	0	0	0	0

The results generated for each economic indicator (i.e. loss in GDP, employment and household income) consist of 10 000 values each (1000 simulated sequences over an analysis period of 10 years). The results are discounted to a present value for the number of years analysed at a selected discount rate. Therefore, each economic indicator now only has a 1000 present values. These values are sorted according to a probability distribution, which can be selected in the yellow cells indicated on the main input sheet shown in Figure 42. Furthermore, a mean or average value is given for each of the 1000 present values per economic indicator. This is for ease of interpretation of the results and comparison purposes when a variety of scenarios are analysed.

	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	55 981	43 457	40 387	545 230	397 221	367 656	23 655	18 366	17 071
1	44 209	34 189	31 432	433 368	320 564	297 736	19 092	14 372	13 296
5	28 519	20 970	19 334	294 413	211 992	192 175	12 058	8 814	8 094
10	20 647	14 529	13 055	221 485	154 696	140 779	8 689	6 077	5 475
15	16 049	11 749	10 655	176 069	125 179	112 765	6 678	4 924	4 461
20	12 602	9 233	8 502	143 535	103 564	94 465	5 240	3 860	3 555
30	9 097	6 398	5 579	107 364	74 724	67 508	3 778	2 658	2 315
40	5 982	4 094	3 775	81 355	56 994	50 891	2 471	1 696	1 560
50	3 652	2 389	2 114	60 052	42 232	37 357	1 507	984	872
60	1 615	1 079	943	34 101	24 249	21 842	664	444	388
70	399	261	231	22 909	14 903	12 763	163	107	95
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	7 430	5 326	4 816	86 843	61 540	55 444	3 109	2 230	2 017

Figure 42: Probability distribution for present values of economic indicators

The lower the mean present value, the better the answer because it indicates an option where the least loss in either GDP, employment and household income occurs as a result of reduced water supply to the irrigation sector. The results shown in Figure 43 can also be illustrated graphically on box-and-whisker plots, which can be selected on the main input sheet. The graphs can be used to illustrate one of the following:

- Values according to the selected probability distribution for the present value at a specific discount rate (as shown in Figure 43).
- Annual values according to the selected probability distribution over the period of the analysis (as shown in Figure 44).

Additionally, graphs for various user priority scenarios can be compared as shown in Figure 44.

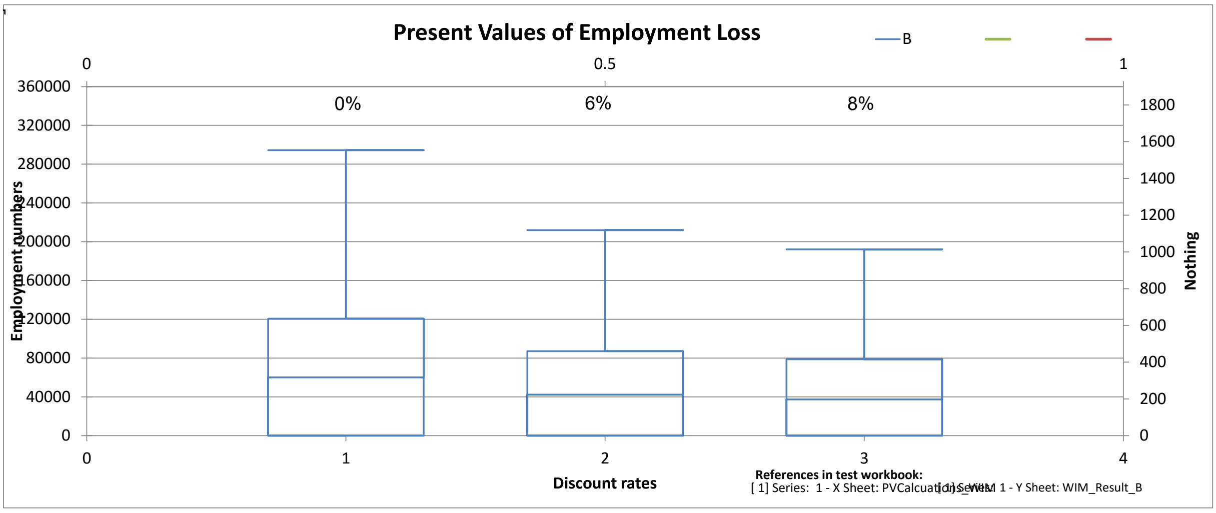


Figure 43: Box plots for present value per discount rate

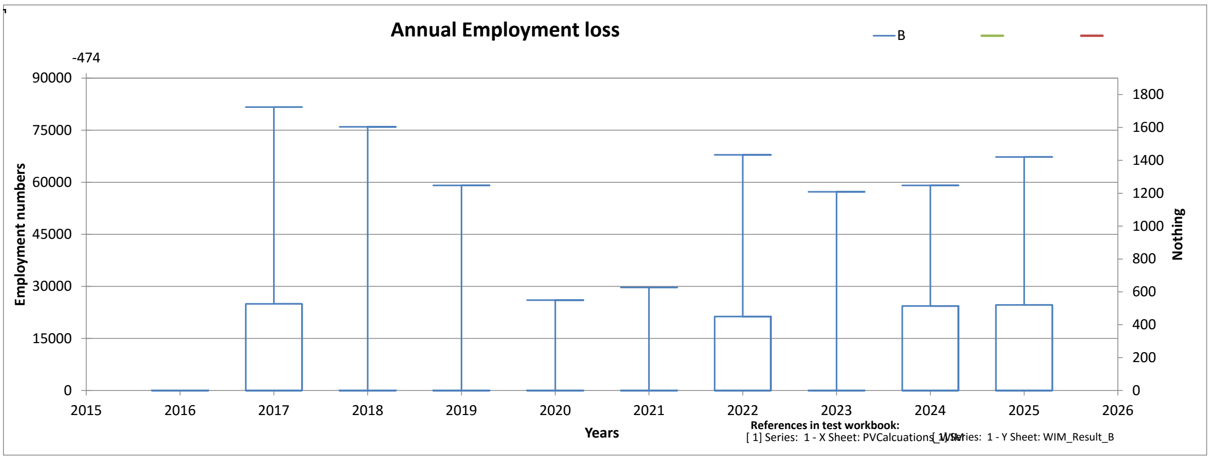


Figure 44: Box plot for annual values over the analysis period

To establish the relationship between the water supply curtailment and the corresponding economic impact thereof, Scenario 1, Scenario 1a and 1b were compared in more detail. These scenarios were configured for a constant development level with no growth in demand on the system over time but with Polihali Dam impounding water from 2022.

Figure 45 illustrates the mean present value at a 0% discount rate for the three different scenarios. Figure 45 it shows that Scenario 1b seems to have resulted in the lowest economic loss in terms of GDP, household income monetary values and employment numbers.

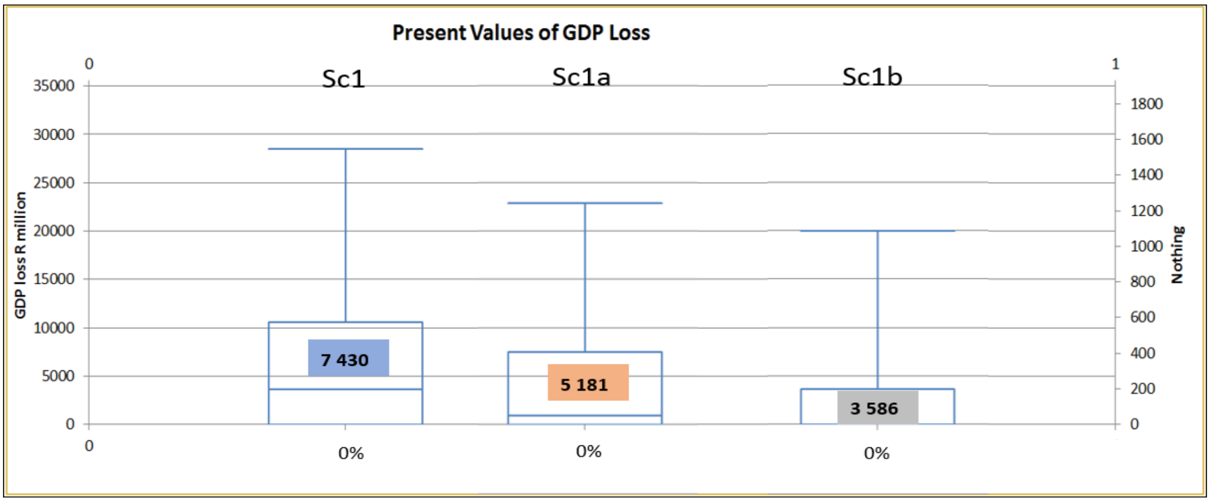


Figure 45: Box plot for mean present value at 0% discount rate for various scenarios

To derive a relationship between each economic indicator and the curtailed water supply volume, the present value for each economic indicator was compared with the present value for the curtailed water supply volume as illustrated in Figure 46.

Table 89 summarises the NPV for each economic indicator (GDP and household income, in R million and employment in numbers) and the corresponding NPV of the curtailed water supply volume (million m³) are given per scenario analysed at different exceedance probabilities. This is for ease of interpretation since it is difficult to tabulate the 1000 simulated values for each economic metric and curtailed water supply volume.

Table 89: Orange River probability distribution (NPV economic indicator vs. curtailment volume)

NPV	Sc1				Sc1a				Sc1b			
Percentiles	GDP	E	HH	Curt Vol	GDP	E	HH	Curt Vol	GDP	E	HH	Curt Vol
0.0%	63860	568329	27064	8804	50220	477767	21185	6864	51710	453529	23317	7339
0.5%	48332	465690	20313	6560	41786	388171	17616	5705	37206	337795	16155	5149
1.0%	44209	433368	19092	6084	38435	364490	16188	5239	33366	312122	14800	4631
5.0%	28519	294413	12058	3905	22880	239533	9627	3117	19947	198546	8611	2708
25.0%	10582	120568	4385	1411	7460	87295	3088	987	3658	51703	1511	479
50.0%	3652	60052	1507	478	890	26890	365	114	0	0	0	0
75.0%	0	0	0	0	0	0	0	0	0	0	0	0
95.0%	0	0	0	0	0	0	0	0	0	0	0	0
99.0%	0	0	0	0	0	0	0	0	0	0	0	0
99.5%	0	0	0	0	0	0	0	0	0	0	0	0
100.0%	0	0	0	0	0	0	0	0	0	0	0	0
Average	7430	86843	3109	999	5185	57965	2171	698	3586	40065	1535	488

GDP = Gross domestic product, E = Employment, HH = Household income, Curt Vol = Curtailment volume

Figure 46 plots the relationship between the NPV GDP loss in R million and the NPV volume of water curtailed in million m³ for the scenarios analysed in the Orange River System at the 2016 constant development level with Polihali Dam in place. Since the discount rate applied for the NPV over a 10-year period is 0%, the NPV for GDP loss and the volume is the sum of the annual GDP loss and volume respectively for 10 years. The relationships take on a second-order polynomial form; however, the R-squared value (fit of the regression line) is not completely 1. From Figure 46, if a volume of 2000 million m³ is curtailed over 10 years, it would result in a GDP loss in the order of R15 billion for all three scenarios during that same period.

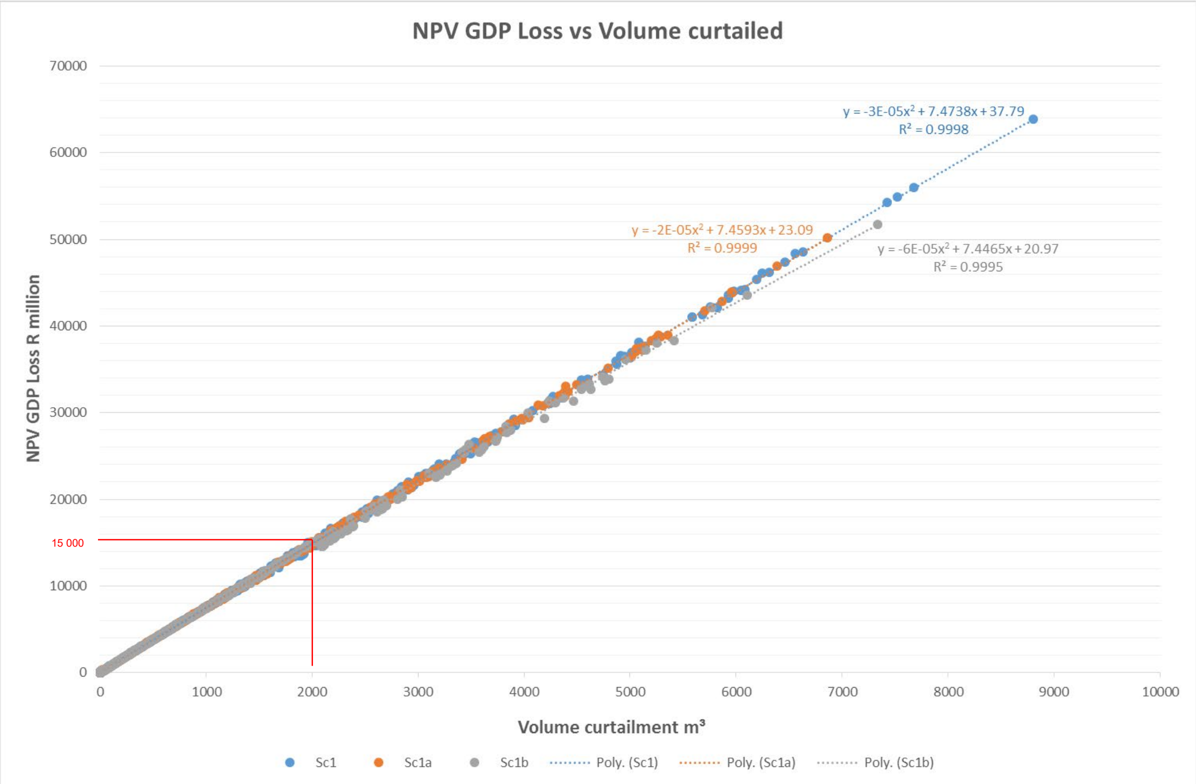


Figure 46: Orange River NPV GDP loss vs. NPV volume curtailed relationship

For the NPV employment loss plotted against the NPV volume curtailed in Figure 47, the relationship for all three scenarios took the form of third-order polynomial equations. However, the R-squared values indicated the fit of the regression lines was less than 0.972. For an NPV volume curtailed of 2000 million m³ over 10 years, there would be an employment loss between 150 000 and 200 000 for all three scenarios.

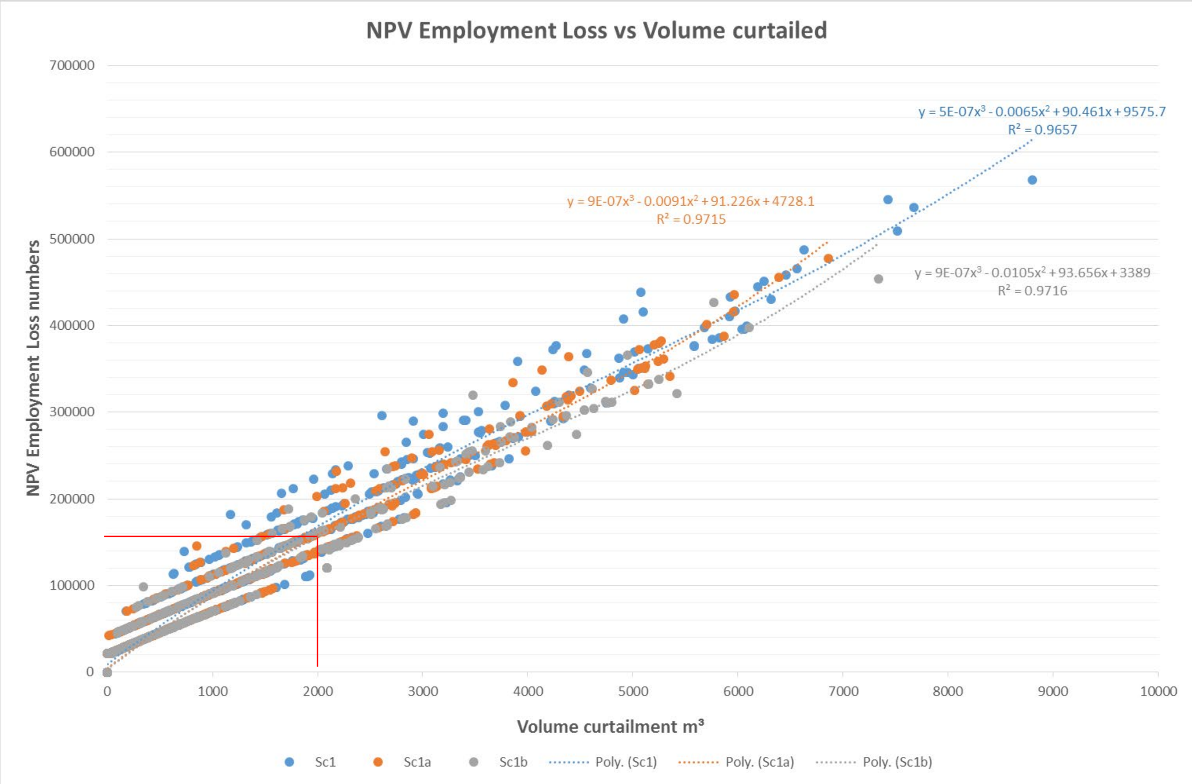


Figure 47: Orange River NPV employment loss vs. NPV volume curtailed relationship

In terms of the NPV of household income loss related to the NPV of the curtailed volume water supply over 10 years, the relationships also took a second-order polynomial form. Linear equations resulted in a similar fit; however, the R-squared value (fit of the regression line) is not completely 1 for either the linear or polynomial equations for Scenario 1 and Scenario 1b. Figure 48 shows that if a volume of 2000 million m³ was curtailed over 10 years, it would result in a household income loss in the order of R6.5 billion for all three scenarios.

Although the objective of the research was to get a single weighted average NPV per economic metric for each scenario over the analysis period, it is important to also consider the annual impact of the water supply curtailment on the economic metrics. Therefore, the 1000 simulated values of each of the economic indicators and curtailed volume water supply to the irrigation sector were plotted against each other for each of the 10 years. This was done for all the scenarios, which were then plotted against one another for comparison.

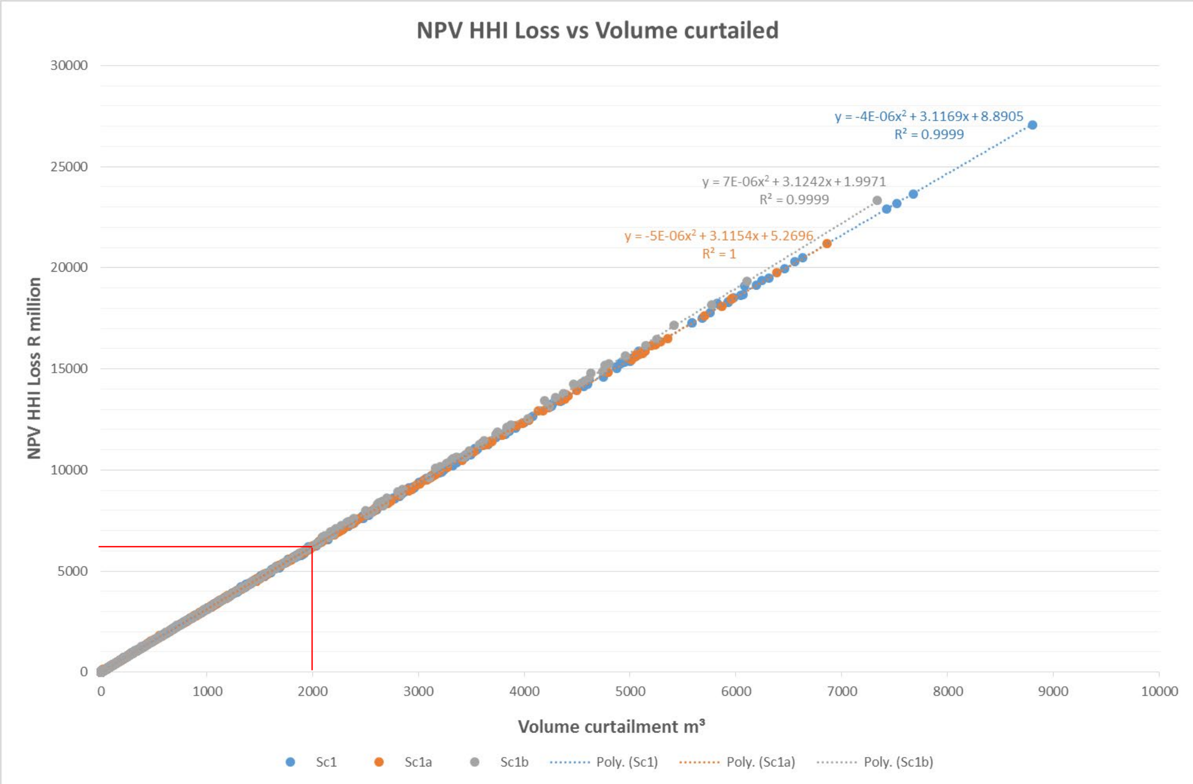


Figure 48: Orange River NPV household income loss vs. average volume curtailed relationship

Figure 49 to Figure 51 indicate the relationships between the annual GDP loss and the volume of water supply curtailment for Scenario 1, Scenario 1a and Scenario 1b respectively. The figures show that the relationships for each of the 10 years, fitted on each other, follow a similar trend. These relationships took on a second-order polynomial form and an average relationship was derived for each scenario (Figure 52). Table 90 summarises the parameters of these relationship equations for each year as well as the average derived equation parameters for the equation type $y = ax^2 + bx + c$.

Table 90: Second-order polynomial equation parameters for GDP Loss

	Scenario 1			Scenario 1a			Scenario 1b		
Year	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**
2016									
2017	−0.0003	7.7539	1.9497	−0.0003	7.7534	0.3522	−0.0004	7.815	0.0708
2018	−0.0003	7.7591	0.3632	−0.0003	7.7537	0.2893	−0.0004	7.8302	0.0277
2019	−0.0003	7.7609	0.1706	−0.0003	7.7557	0.4343	−0.0004	7.8440	0.1459
2020	−0.0003	7.7581	0.7815	−0.0003	7.7546	0.2897	−0.0004	7.8332	0.0421
2021	−0.0003	7.7590	0.6652	−0.0003	7.7532	0.1363	−0.0004	7.8329	0.0744
2022	−0.0003	7.7546	1.1018	−0.0003	7.7572	0.6394	−0.0004	7.8301	0.0360
2023	−0.0003	7.7531	1.0705	−0.0003	7.7622	0.7535	−0.0004	7.8180	0.1563
2024	−0.0003	7.7582	1.1549	−0.0003	7.7549	0.9951	−0.0004	7.8246	0.4772
2025	−0.0003	7.7575	1.0071	−0.0003	7.7575	1.0210	−0.0004	7.8213	0.1671
Avg.	**−0.0003**	**7.7572**	**0.9183**	**−0.0003**	**7.7558**	**0.5456**	**−0.0004**	**7.8277**	**0.1331**

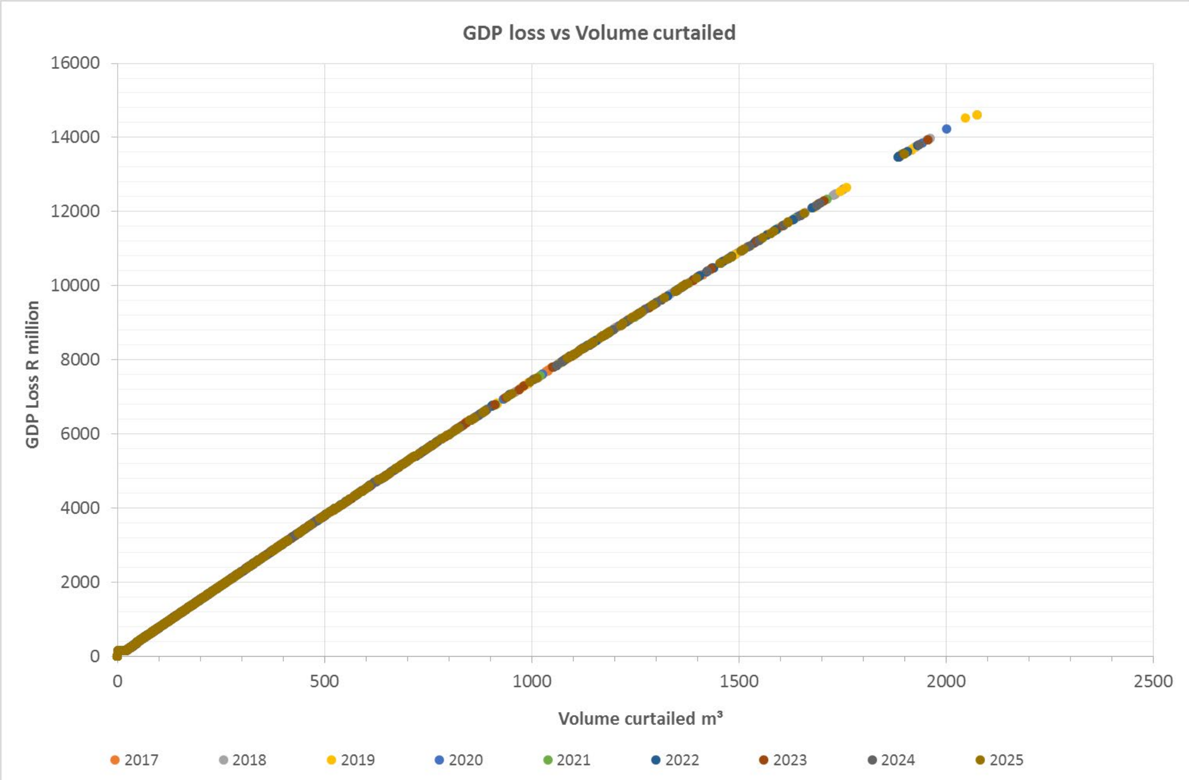


Figure 49: GDP loss – Volume curtailed relationship per annum (Scenario 1)

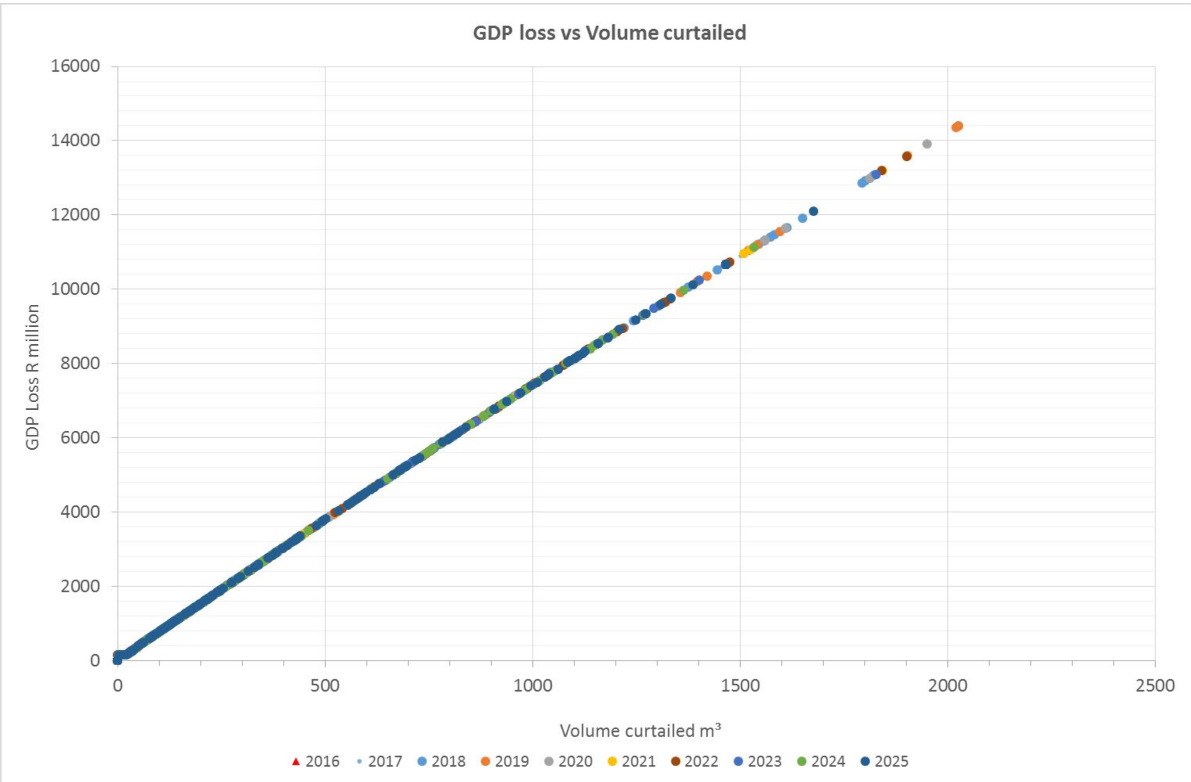


Figure 50: GDP loss – Volume curtailed relationship per annum (Scenario 1a)

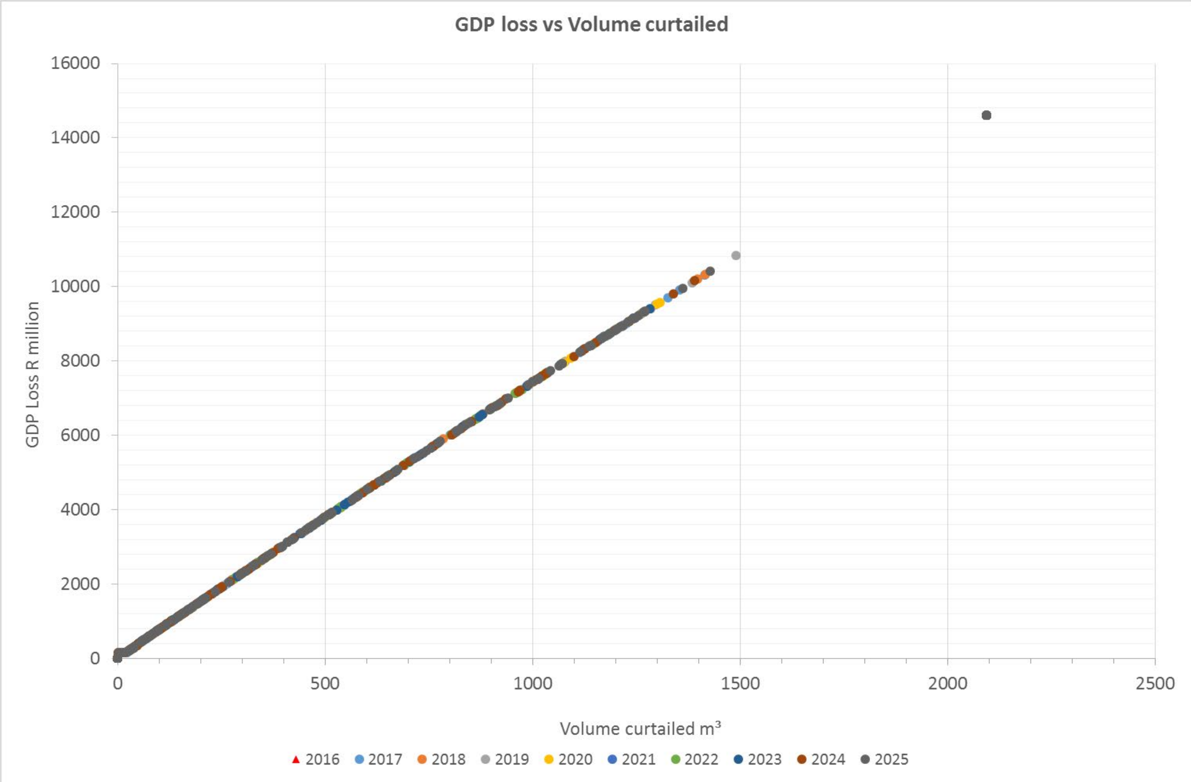


Figure 51: GDP loss – Volume curtailed relationship per annum (Scenario 1b)

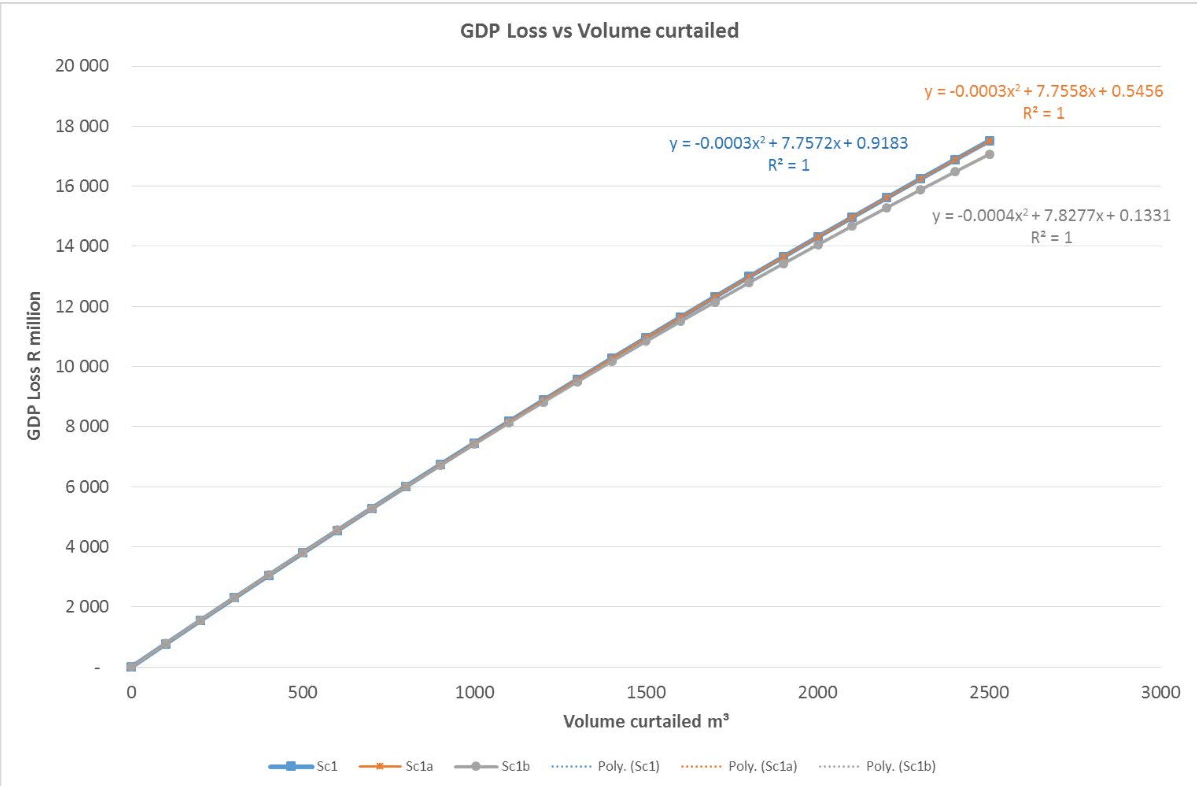


Figure 52: Average derived GDP loss – Volume curtailed relationship

Figure 53 to Figure 55 indicate the relationships between the annual employment loss and the volume of water supply curtailment for Scenario 1, Scenario 1a and Scenario 1b respectively. The figures show that the relationships for each of the 10 years, fitted on each other, follow a similar trend. These relationships took a third-order polynomial form and an average relationship was derived for each scenario (Figure 56). Table 91 summarises the parameters of these relationship equations for each year as well as the average derived equation parameters for the equation type $y = ax^3 + bx^2 + cx + d$.

Table 91: Third-order polynomial equation parameters for employment loss

	Scenario 1				Scenario 1a				Scenario 1b			
Year	**a**	**b**	**c**	**d**	**a**	**b**	**c**	**d**	**a**	**b**	**c**	**d**
2016												
2017	3E-05	−0.106	144.1	1 310.8	6E-05	−0.156	162.9	353.1	3E-05	−0.119	154.6	440.0
2018	3E-05	−0.095	138.4	536.93	3E-05	−0.089	135.6	334.6	3E-05	−0.098	140.5	213.0
2019	3E-05	−0.105	145.7	386.23	2E-05	−0.084	132.5	276.5	3E-05	−0.101	144.7	267.4
2020	3E-05	−0.105	145.2	339.26	3E-05	−0.100	141.0	110.9	3E-05	−0.108	150.0	86.5
2021	4E-05	−0.129	158.5	403.74	3E-05	−0.095	134.6	70.0	3E-05	−0.115	151.2	103.9
2022	4E-05	−0.117	150.0	1 141.3	4E-05	−0.122	152.2	471.3	3E-05	−0.108	146.0	331.5
2023	4E-05	−0.129	153.4	1 004.5	5E-05	−0.145	160.4	534.1	4E-05	−0.122	153.1	382.2
2024	5E-05	−0.134	154.6	1 367.4	7E-05	−0.175	171.6	577.9	4E-05	−0.120	153.5	583.3
2025	5E-05	−0.133	154.1	1 075.6	6E-05	−0.168	169.8	739.0	3E-05	−0.101	142.5	512.8
Avg	**3.8E-05**	**−0.117**	**149.3**	**840.6**	**4.3E-05**	**−0.126**	**151.2**	**385.3**	**3.2E-05**	**−0.110**	**148.5**	**324.5**

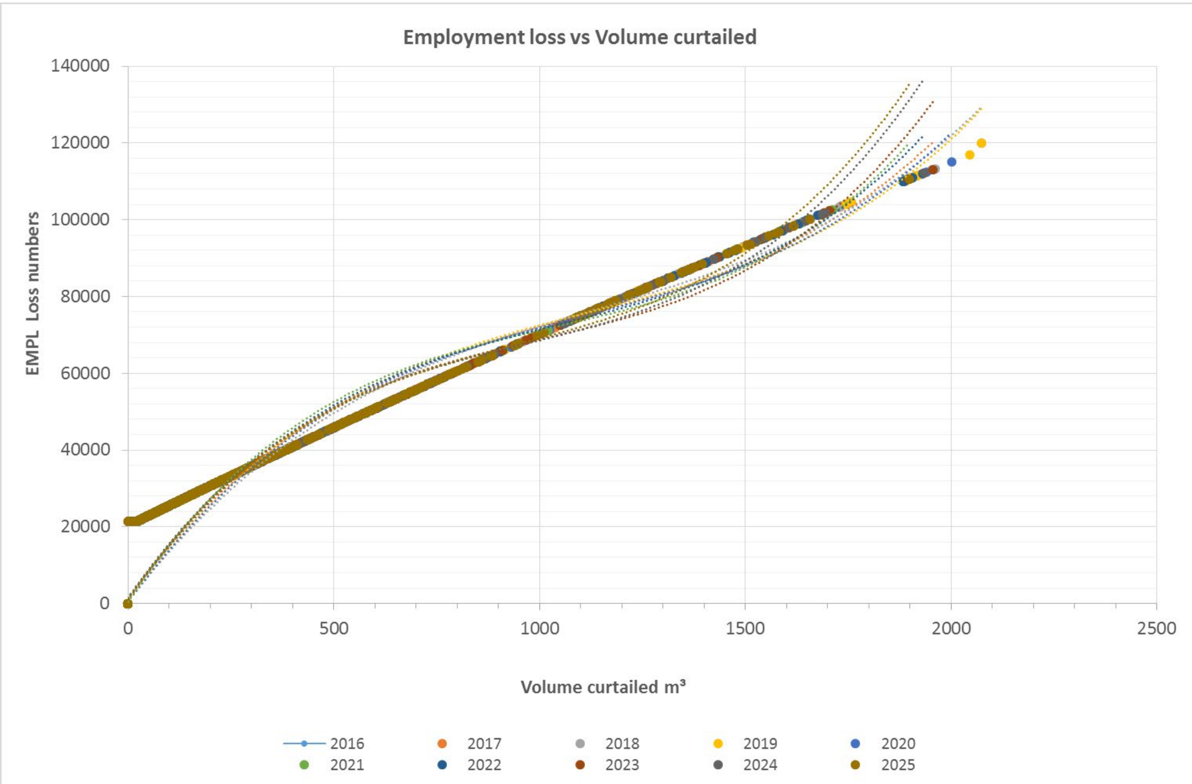


Figure 53: Employment loss – Volume curtailed relationships per annum (Scenario 1)

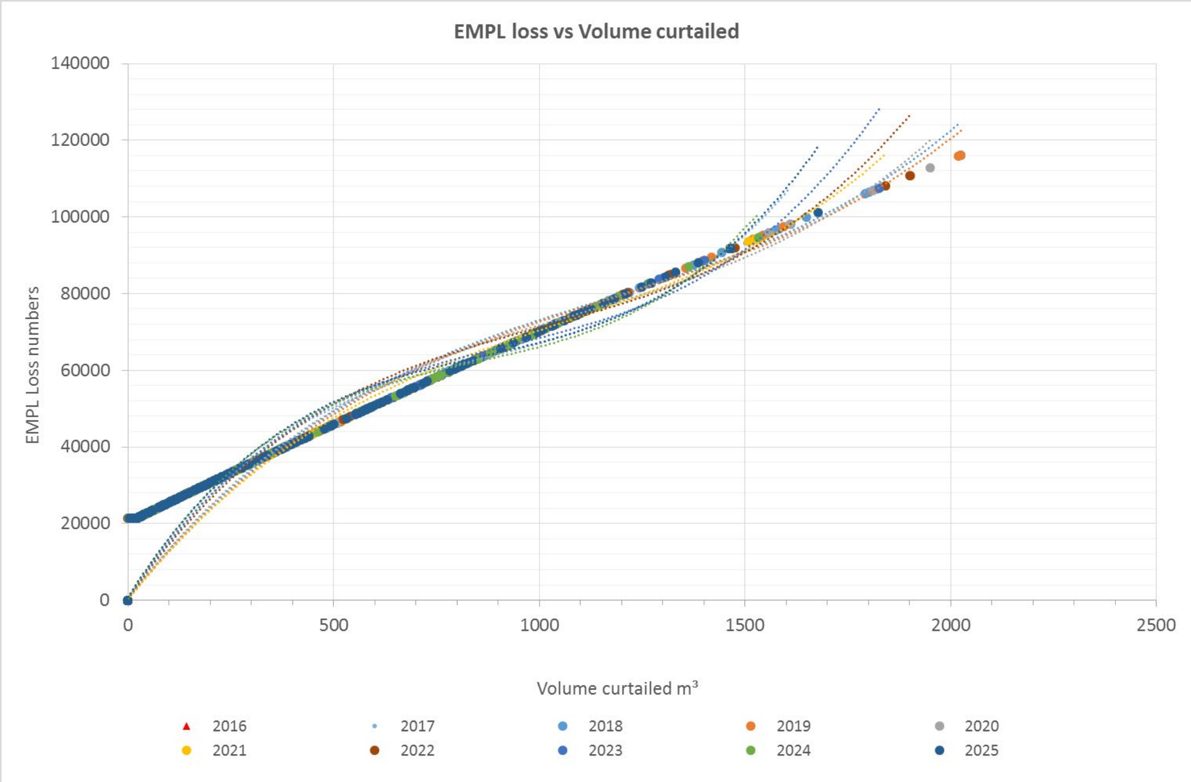


Figure 54: Employment loss – Volume curtailed relationships per annum (Scenario 1a)

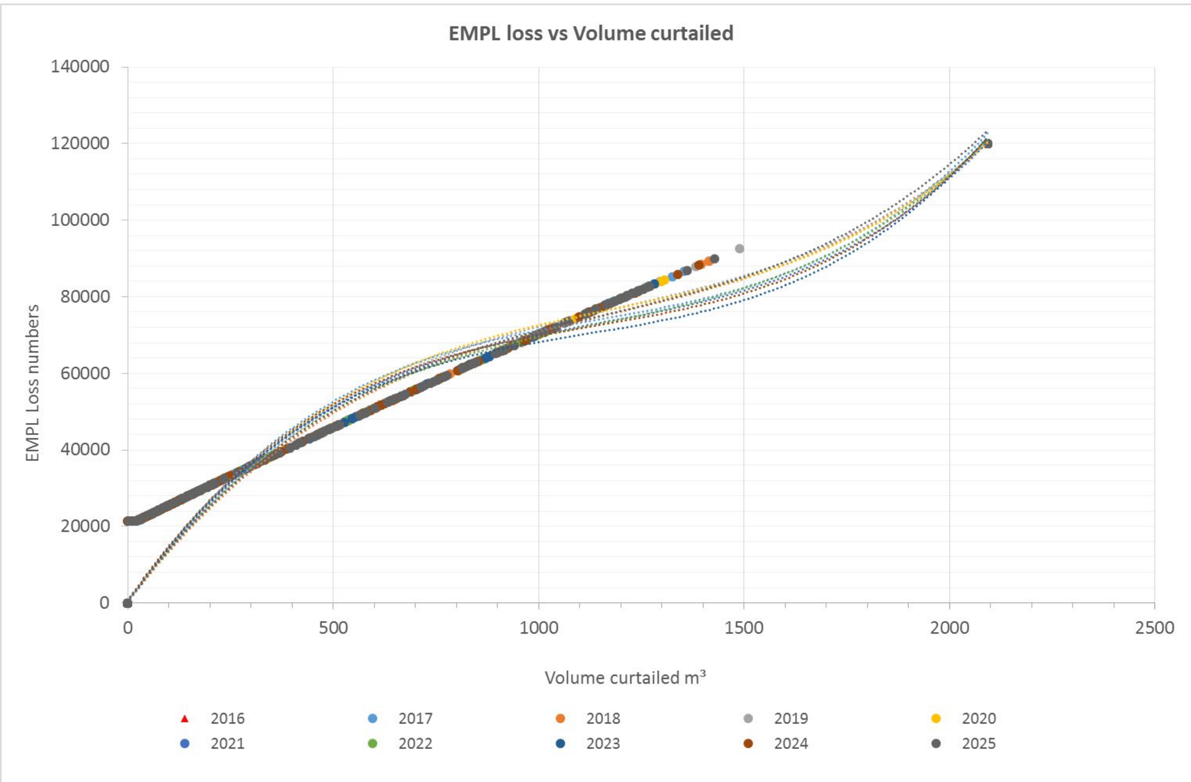


Figure 55: Employment loss – Volume curtailed relationships per annum (Scenario 1b)

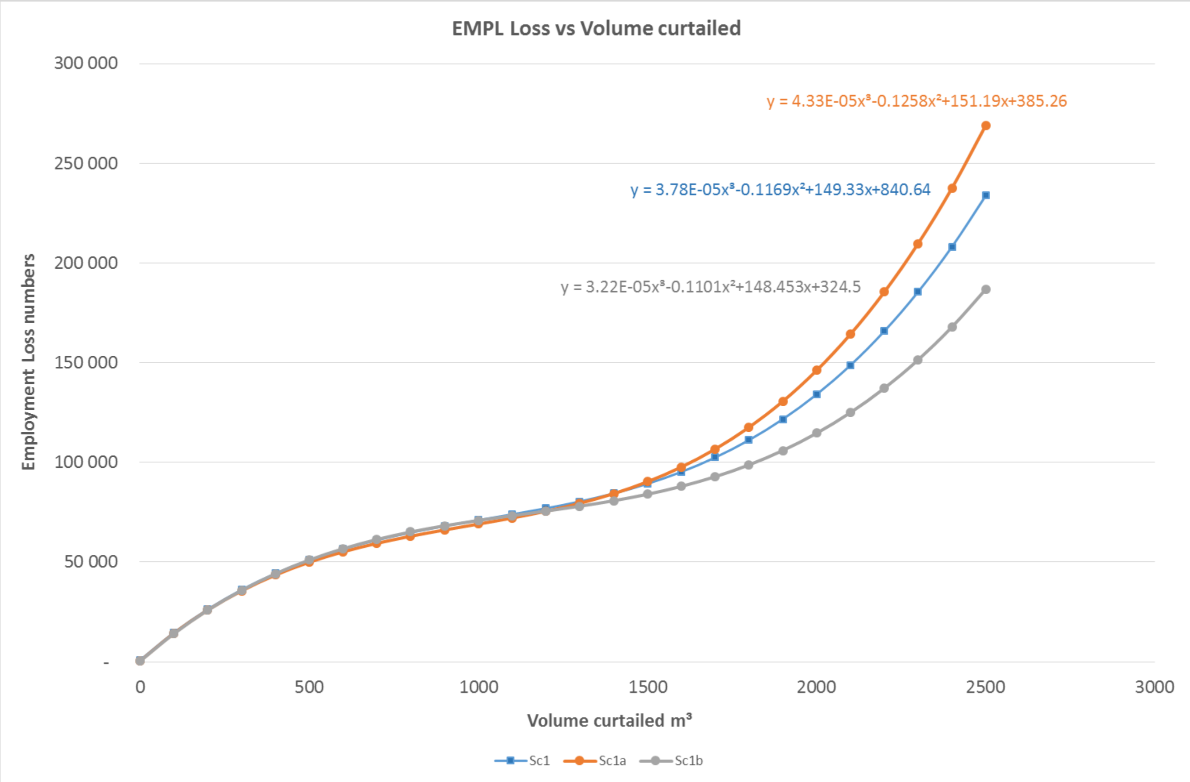


Figure 56: Average derived Employment Loss – Volume curtailed relationship

Table 92 summarises the parameters of these relationship equations for each year as well as the average derived equation parameters for the equation type $y = ax^2 + bx + c$.

Table 92: Second-order polynomial equation parameters for household income loss

	Scenario 1			Scenario 1a			Scenario 1b		
Year	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**
2016									
2017	-6E-05	3.1731	0.7933	-6E-05	3.1729	0.1432	4E-05	3.0827	0
2018	-4E-05	3.1508	0.4817	-6E-05	3.1730	0.1175	6E-05	3.0641	0.6108
2019	-4E-05	3.1465	0.3201	-6E-05	3.1739	0.1771	7E-05	3.0416	0.5656
2020	-6E-05	3.1749	0.3191	-6E-05	3.1735	0.1185	6E-05	3.0482	0.2780
2021	-7E-05	3.1751	0.2711	-6E-05	3.1729	0.0556	5E-05	3.0725	0.2588
2022	-6E-05	3.1735	0.4884	-6E-05	3.1743	0.2603	5E-05	3.0714	0.7263
2023	-6E-05	3.1729	0.4341	-6E-05	3.1764	0.3049	4E-05	3.0843	0.7457
2024	-7E-05	3.1749	0.6291	-6E-05	3.1734	0.4063	5E-05	3.0749	1.2303
2025	-7E-05	3.1746	0.4094	-6E-05	3.1745	0.4148	3E-05	3.080	1.1165
Avg	**-6E-05**	**3.1685**	**0.4607**	**-6E-05**	**3.1739**	**0.2220**	**5E-05**	**3.0689**	**0.6147**

Figure 57 to Figure 59 indicate the relationships between the annual household income loss and the volume of water supply curtailment for Scenario 1, Scenario 1a and Scenario 1b respectively. The figures show that the relationship for each of the 10 years, fitted on each other, follows a similar trend. These relationships took a second-order polynomial form and an average relationship was derived for each scenario (Figure 60).

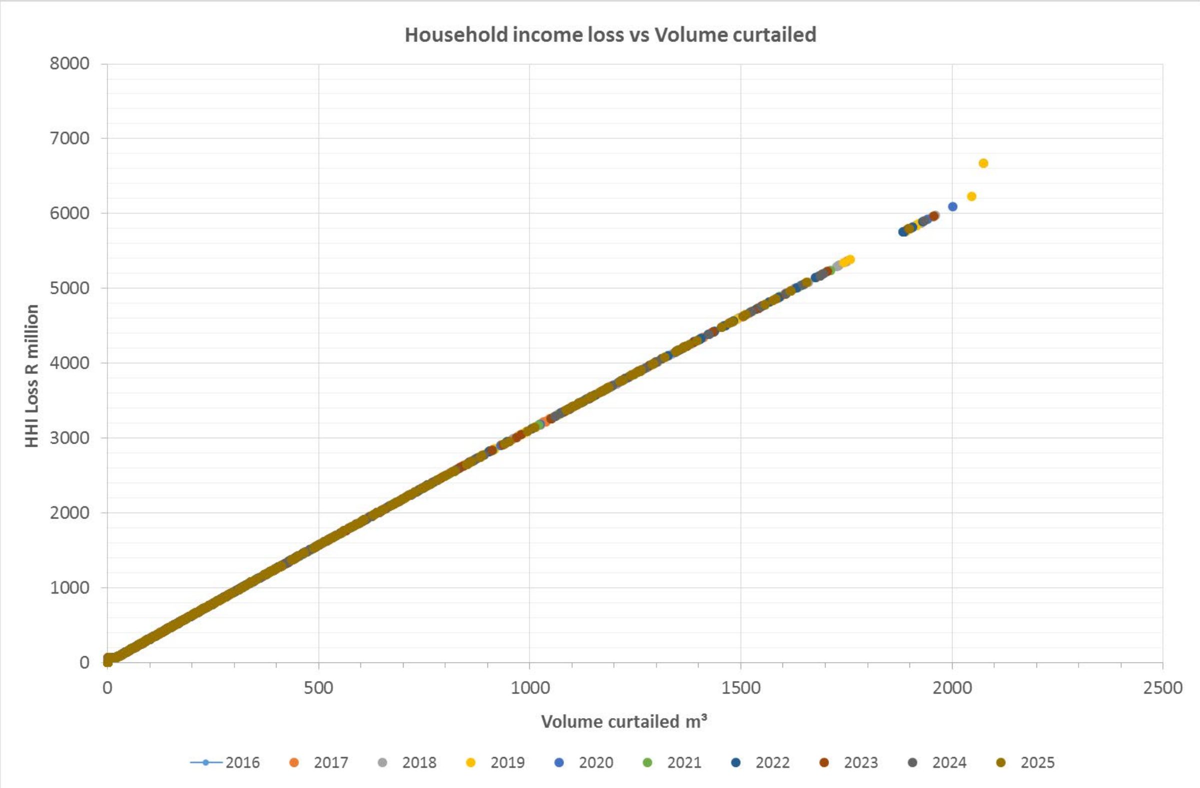


Figure 57: Household income loss – Volume curtailed relationships per annum (Scenario 1)

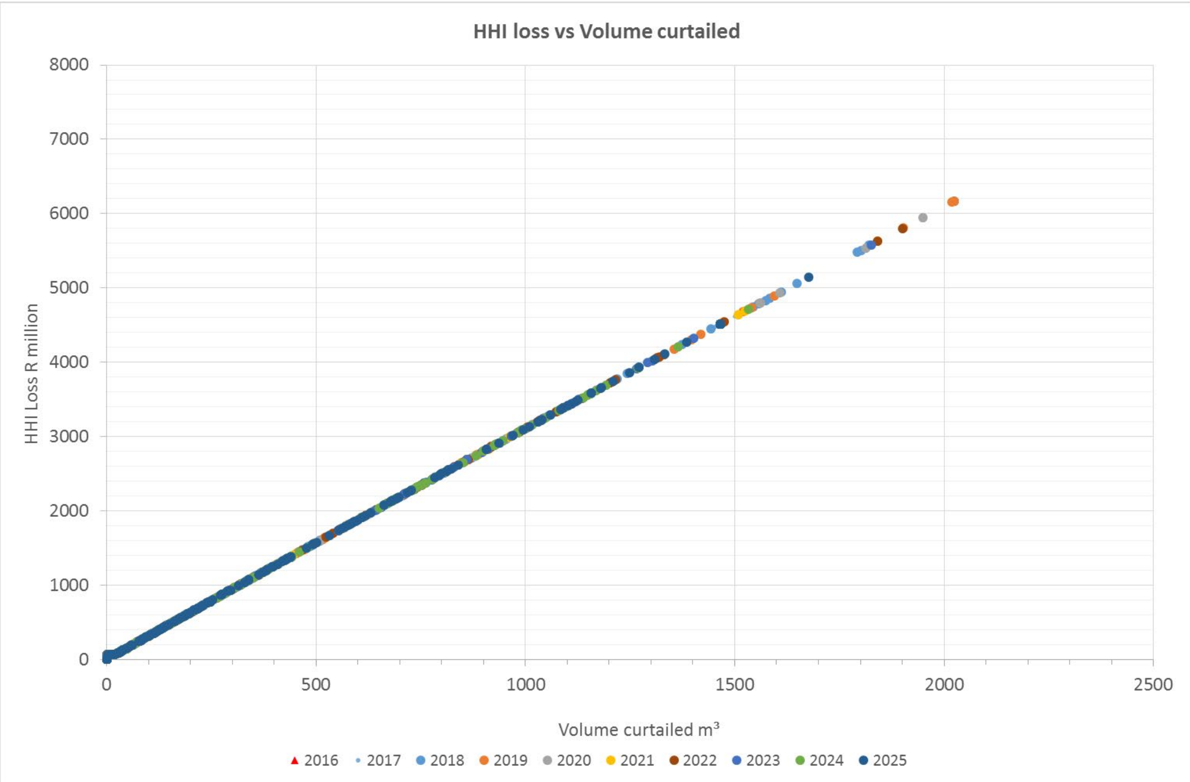


Figure 58: Household income loss – Volume curtailed relationships per annum (Scenario 1a)

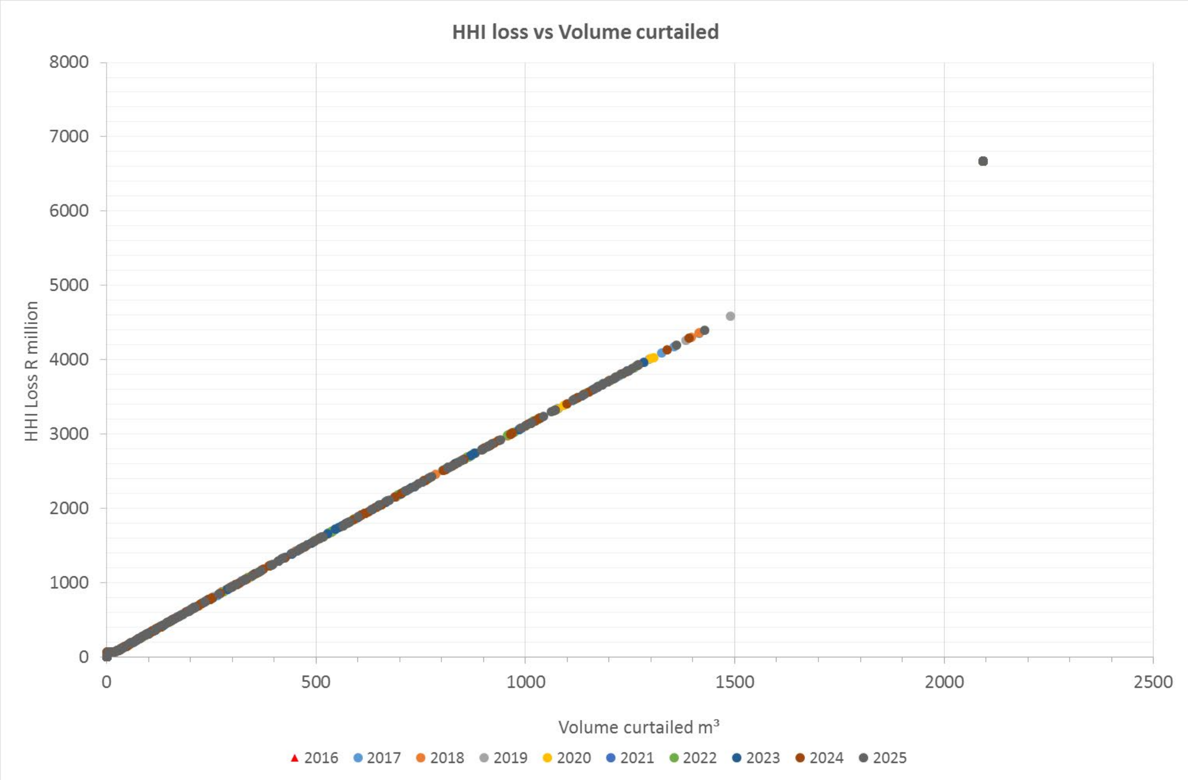


Figure 59: Household income loss – Volume curtailed relationships per annum (Scenario 1b)

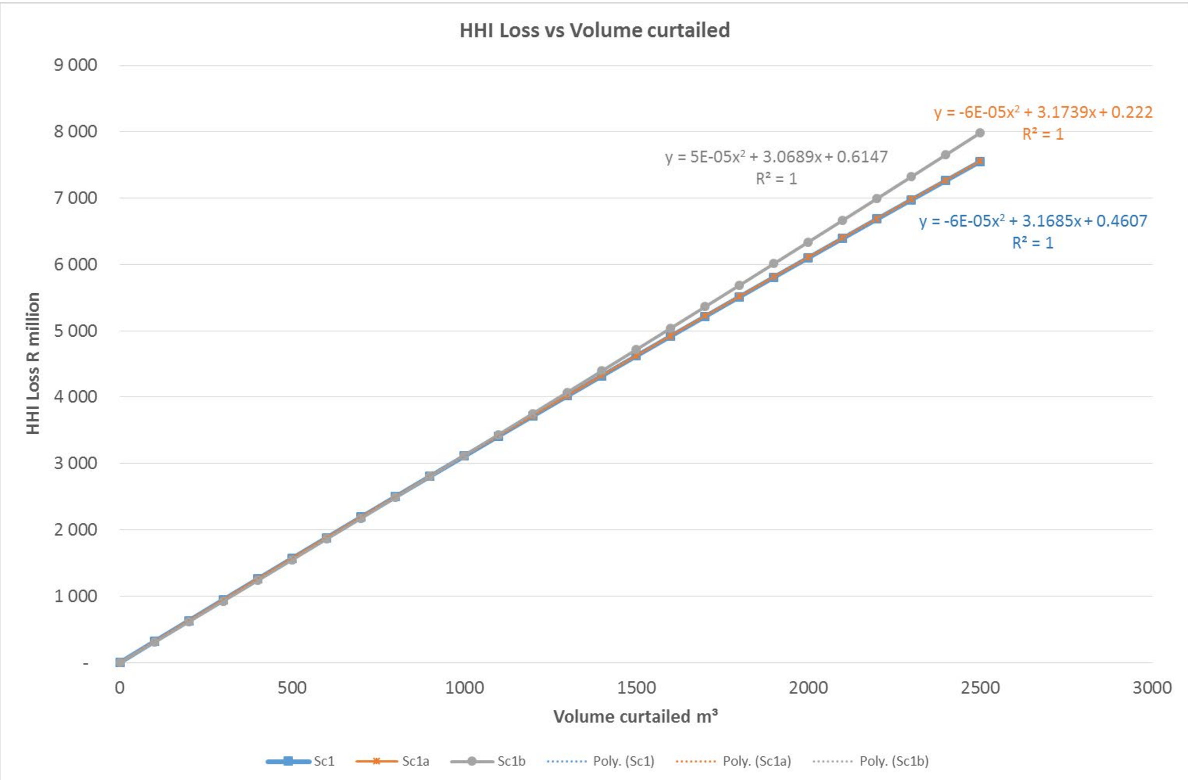


Figure 60: Average derived household income loss – Volume curtailed relationship

Since it is impractical to tabulate 1000 values, the annual average at different exceedance probabilities for each economic metric was listed against the annual average volume curtailed for the same set of exceedance probabilities as shown in Table 93.

Table 93: Orange River probability distribution (annual average economic indicator vs. curtailment volume)

Annual AVG	Sc1				Sc1a				Sc1b			
Percentiles (%):	GDP	E	HH	Curt Vol	GDP	E	HH	Curt Vol	GDP	E	HH	Curt Vol
0.0%	12 602	102 628	5 473	1 772	11 741	96 474	5 008	1 638	13 147	108 034	6 006	1883.7
0.5%	**11 062**	**92 025**	**4 706**	**1 536**	**9 787**	**83 647**	**4 141**	**1 345**	**11 022**	**93 026**	**4 902**	**1552.582**
1.0%	**9 829**	**83 911**	**4 163**	**1 354**	**9 295**	**80 401**	**3 926**	**1 274**	**8 646**	**76 575**	**3 736**	**1192.591**
5.0%	**5 089**	**52 403**	**2 126**	**683**	**3 998**	**41 055**	**1 665**	**533**	**2 323**	**29 818**	**961**	**305.7266**
25.0%	213	9 525	87	27	-	-	-	-	-	-	-	-
50.0%	-	-	-	-	-	-	-	-	-	-	-	-
75.0%	-	-	-	-	-	-	-	-	-	-	-	-
95.0%	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
99.0%	-	-	-	-	-	-	-	-	-	-	-	-
99.5%	-	-	-	-	-	-	-	-	-	-	-	-
100.0%	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Average	**743**	**8684**	**311**	**100**	**518**	**5797**	**217**	**70**	**359**	**4006**	**154**	**49**

For Scenario 1, there are three levels of curtailment with up to a 25% probability of curtailment at Level 1 over a 10-year period, between 5% and 1% probability of curtailment at Level 2 and less than 0.5% probability of curtailment at Level 3.

For Scenario 1a, there are two levels of curtailment with between a 1% and 0.5% probability of curtailment at Level 1 and less than 0.5% probability of curtailment at Level 2.

For Scenario 1b, there is only one level of curtailment with a 5% probability of being curtailed and the risk of being curtailed completely.

Table 94 lists the annual average loss in GDP for a variety of exceedance probabilities for Scenario 1. For this scenario, there was up to a 25% probability of an average GDP loss of R213 million, which corresponds to the probability of water supply to be curtailed on average with 27 million m³ as can be seen in Table 93.

Table 94: Orange River probability distribution for annual average loss in GDP (Scenario 1)

Percentile	Loss in GDP R million										
	average	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0%	12 602	0	13 927	14 610	14 610	14 235	13 546	13 782	13 944	13 799	13 563
0.5%	11 062	0	13 564	13 601	13 526	11 060	11 509	13 473	11 247	11 230	11 416
1%	9 829	0	13 489	12 443	12 205	8 911	9 163	11 360	10 031	9 977	10 715
5%	5 089	0	**9 164**	**8 308**	**5 779**	**861**	**1 398**	**7 097**	**5 502**	**5 778**	**7 005**
25%	213	0	699	0	0	0	0	163	0	613	654
50%	0	0	0	0	0	0	0	0	0	0	0
75%	0	0	0	0	0	0	0	0	0	0	0
95%	0	0	0	0	0	0	0	0	0	0	0
99%	0	0	0	0	0	0	0	0	0	0	0
99.5%	0	0	0	0	0	0	0	0	0	0	0
100%	0	0	0	0	0	0	0	0	0	0	0

The different priority classifications that were compared for the irrigation sector per level of curtailment for each of the different scenarios are listed in Table 95.

Table 95: Orange River System irrigation curtailment proportions

Scenario	Risk curtailment levels	1/10	1/20	1/100	1/200	Total
1	**Proportion**	–	0.5	0.4	0.1	**1**
	Volume (million m³)	–	1046.5	837.2	209.3	**2 093**
1a	**Proportion**	0.7	0	0.3	0	**1**
	Volume (million m³)	1 465.1	0	627.9	0	**2 093**
1b	**Proportion**	1.0	0	0	–	**1**
	Volume (million m³)	2 093	0	0	–	**2093**

The total GDP contribution of irrigation agriculture in the Orange River System is R14 116 million, its total contribution to employment numbers is 148 442 and its total contribution to household income is R11 004 million. For water supply curtailments below 500 million m³, there are not significant differences in the economic impact among the scenarios. However, for Scenario 1b, all irrigation water is supplied at a higher risk of being curtailed than with Scenario 1 and Scenario 1a. More significant differences are evident the larger the volume of water that is supplied is curtailed.

Table 96 summarises the loss for each economic indicator per scenario at curtailment volume intervals of 500 million m³. Both losses in GDP and employment numbers are always less for Scenario 1b; however, in terms of the loss in household income, there is a bigger loss in household income for Scenario 1b than for the other scenarios for a water supply curtailment of 1000 million m³ and more.

Table 96: Economic metric loss per volume of curtailment per scenario

Volume curtailed (million m³)	GDP loss (R million)			Employment loss numbers			Household income loss (R million)		
	Sc 1	Sc 1a	Sc 1b	Sc 1	Sc 1a	Sc 1b	Sc 1	Sc 1a	Sc 1b
500	3 804	3 803	3 814	51 005	49 944	51 057	1 570	1 572	1 548
1000	7 458	7 456	7 428	71 053	69 091	70 912	3 110	3 114	3 119
1 500	10 962	10 959	10 842	89 317	90 327	84 056	4 621	4 626	4 716
2000	14 315	14 312	14 056	134 132	146 152	114 656	6 102	6 108	6 338
2 500	17 519	17 515	17 069	233 830	269 066	186 877	7 554	7 560	7 985

Figure 61 illustrates the storage projection plot for the combined Gariep and Vanderkloof dams (Orange River) over a 10-year period with the starting storage of 56.6% in May 2016. The box-and-whisker plots indicate the probability distribution of the system storage for each month over the 10-year analysis period. The system has a dead storage capacity of 1638 million m³. There is a probability for the system storage to be reduced to this capacity twice over the analysis period i.e. 2018 and 2019. These are also the years with the probabilities for the most severe curtailments levels, however unlikely.

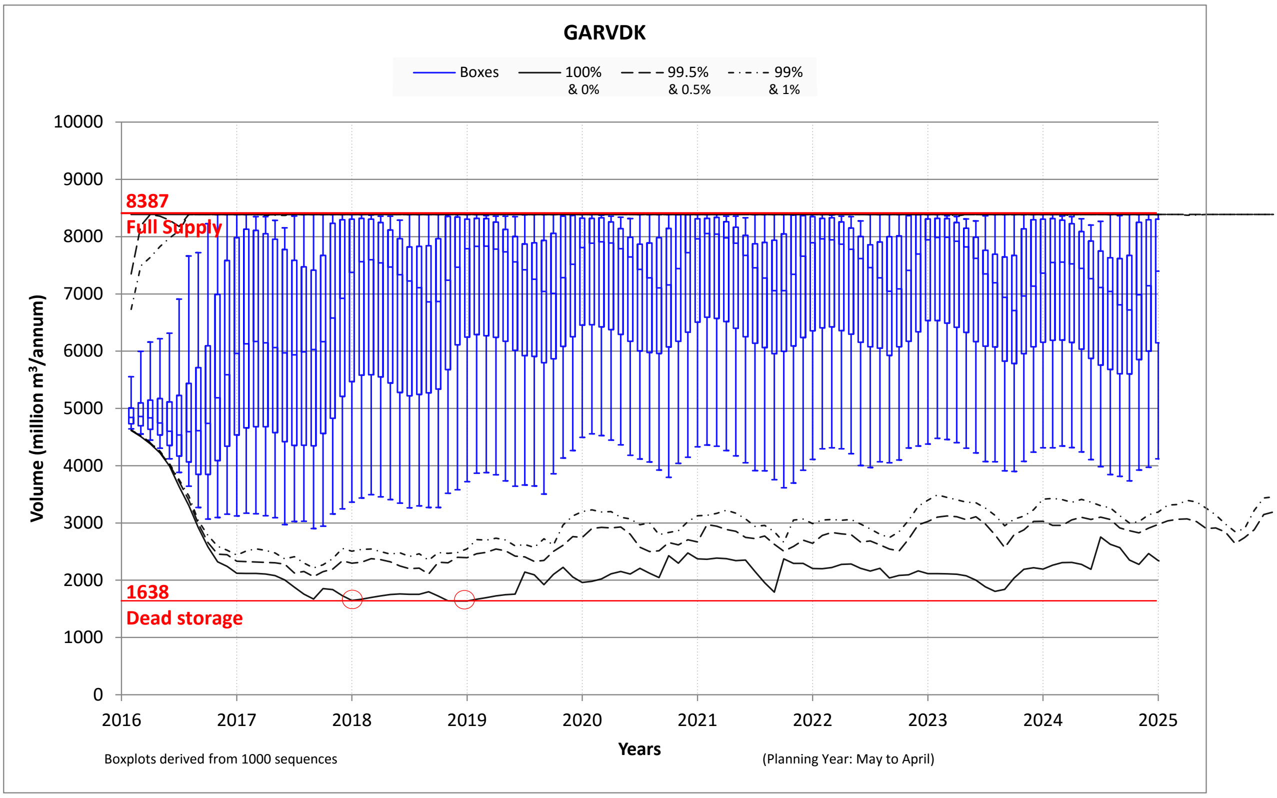


Figure 61: Storage plot for the Orange River System (Scenario 1)

6 RESULTS

The results obtained from the scenario analyses undertaken are discussed in this section. One part of the results entails determining if the water resource systems would be able to supply the demand based on the starting storages at the given development level. The analyses were either executed using the WRYM or WRPM from where the `plt.out` and `dem.out` or `sys.out` files were generated respectively as output. The `sys.out` file indicates the level of curtailments required for each of the 1000 simulated sequences per year analysed whereas the `plt.out` and `dem.out` indicate the available supply versus demand for each of the 1000 simulated sequences per year analysed.

The second part of the results consists of the impact that the change in water supply has on the economic indicators (i.e. GDP, employment numbers and household income), which is determined by means of the WIM based on 2016 crop prices. Lastly, the output from the water resource models and the WIM are incorporated in the ASM, where the present values at given discount rates for each economic indicator are calculated and illustrated graphically by means of a probability distribution box-and-whisker plots.

6.1 Orange River System

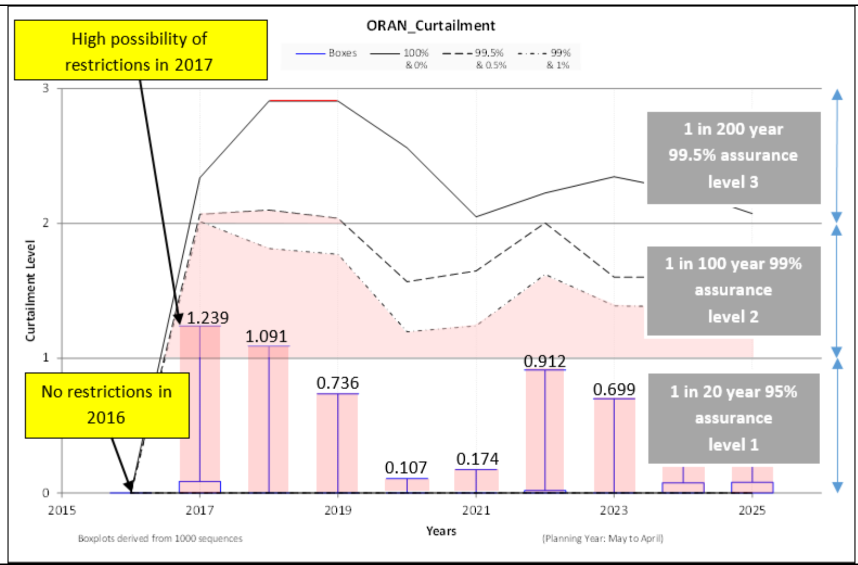
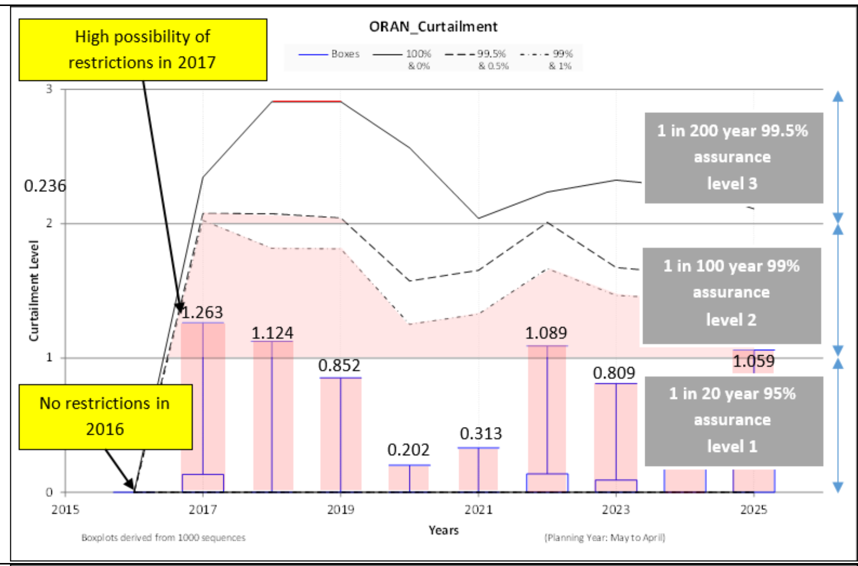
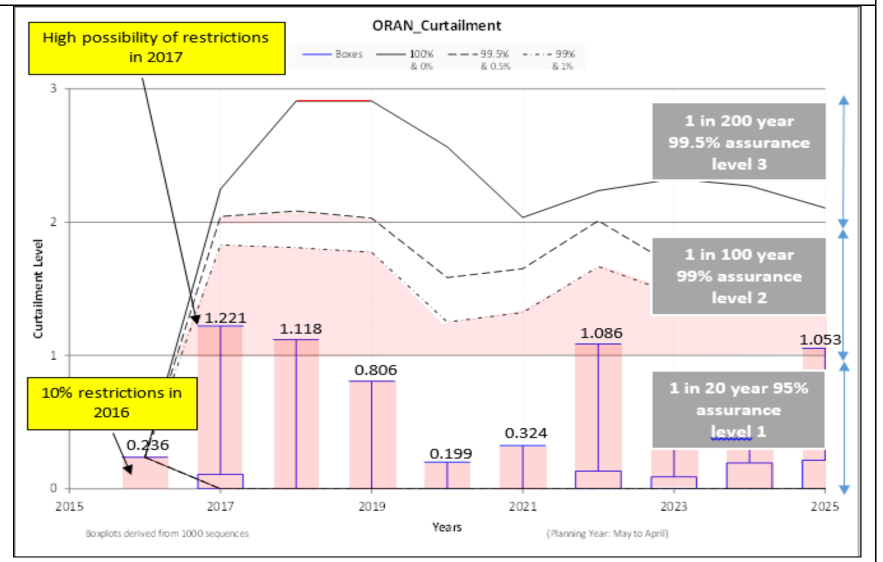
6.1.1 Water supply curtailment

The system curtailment as well as the storage projection plots for all the scenarios analysed in the Orange River System are presented in Table 97 and Table 98 respectively.

Nine different scenarios were analysed for the Orange River System. The alternative assurance of supply requirements indicated an improvement in terms of the timing of curtailments as well as the violation of the curtailment criteria. The system curtailment as well as the storage projection plots for all the scenarios analysed in the Orange River System are presented in Table 97 and Table 98 respectively. Among the nine scenarios analysed, Scenario 3a was the only scenario indicating curtailments required in the first year (2016) already. Ideally, the various assurance of supply criteria options have to be compared for the same scenario i.e. Scenario 1, Scenario 2 or Scenario 3. With the first alternative assurance of supply criteria (Scenario 3), however, the need for curtailments was only required in 2017. The storage projection though, indicated a more frequent drop to the dead storage level than for the original assurance of supply criteria.

For the second alternative assurance of supply criteria, the curtailment requirement at, for example, a 5% probability was less than for the alternative assurance of supply options, but the storage projection indicated a more frequent drop to dead storage level. It can be seen from the socio-economic results in Section 6.1.2 that the second alternative assurance of supply option has the smallest impact on economic indicators. It is important however that the behaviour of the water resource in terms of its storage also be considered before final decision pertaining to the assurance of supply requirements for the specific system is made.

Table 97: Curtailment of water supply over a 10-year period

<table>
<tr><th>User Priority</th><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th></tr>
<tr><td>Original</td>
<td></td>
<td></td>
<td></td></tr>
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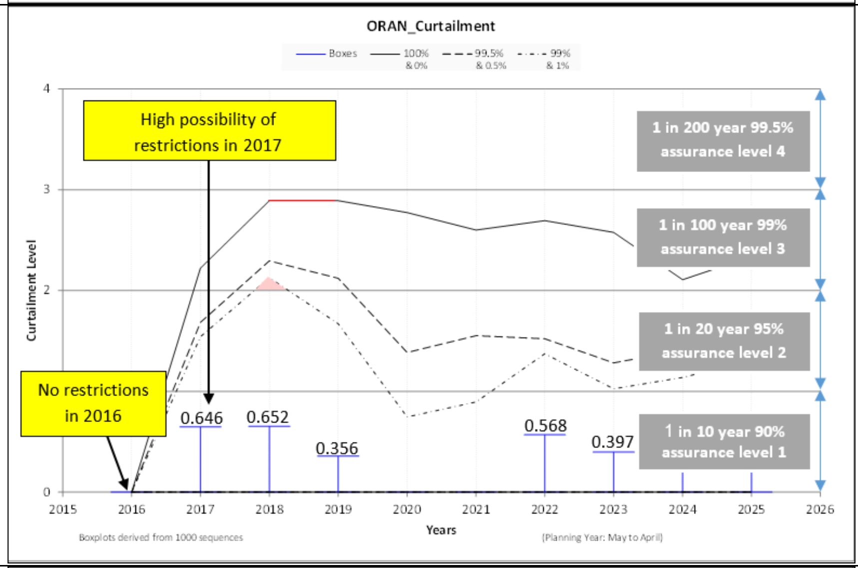
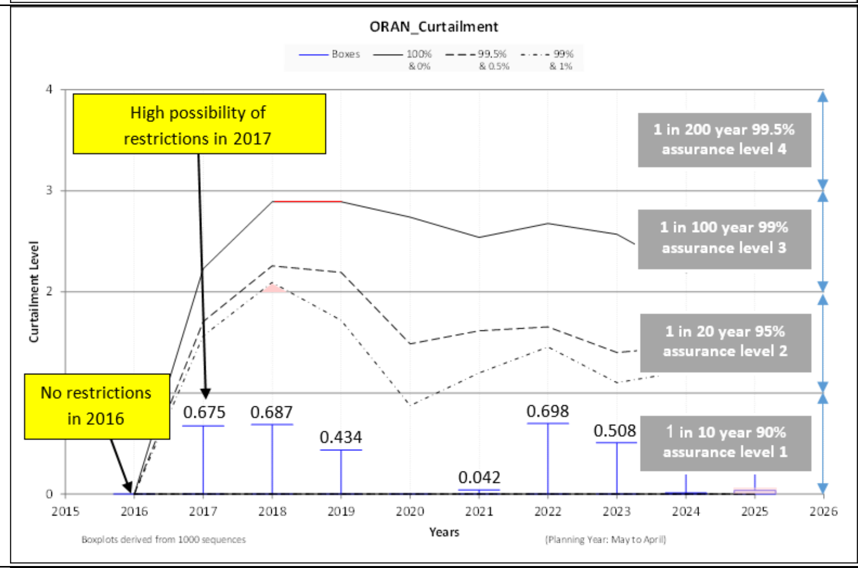
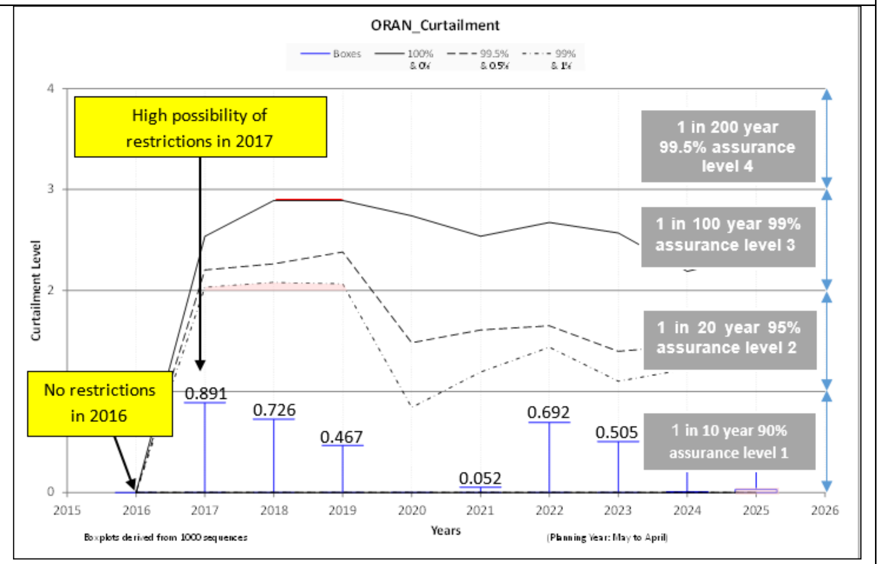
<td></td>
<td></td>
<td></td></tr>
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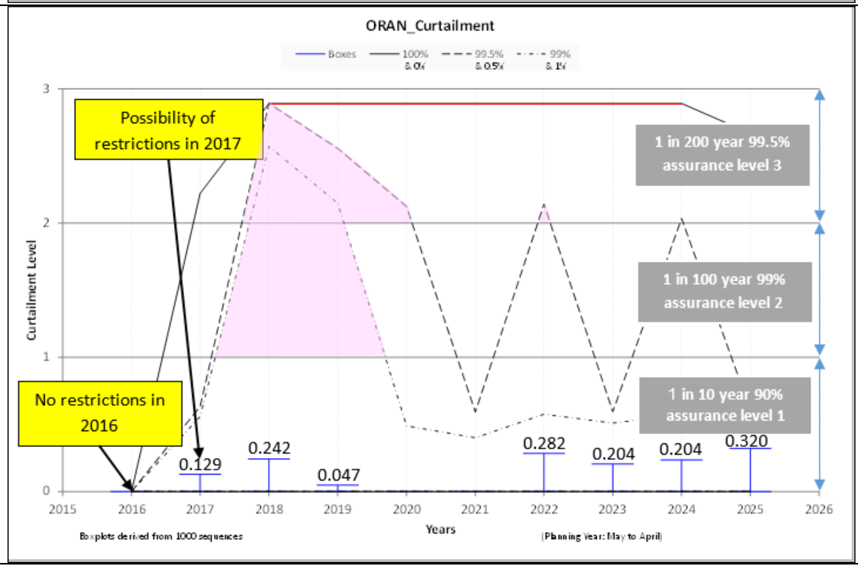
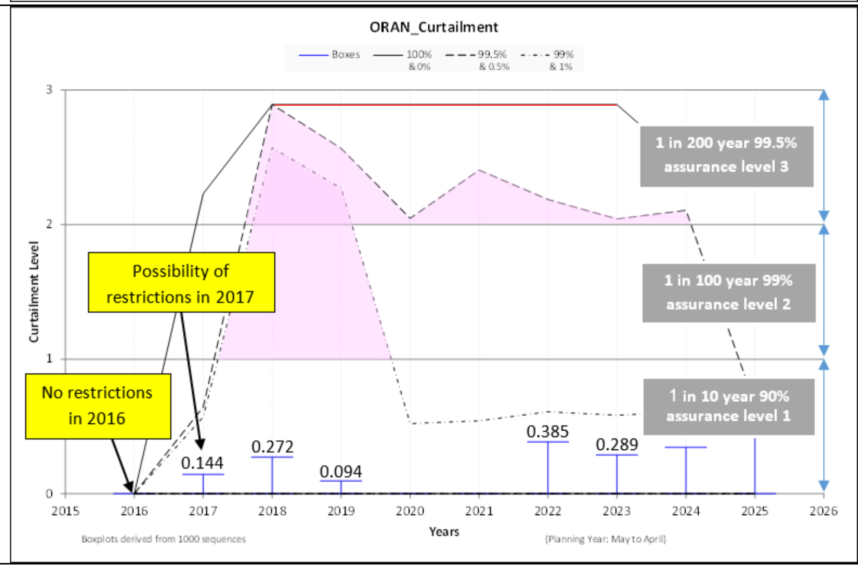
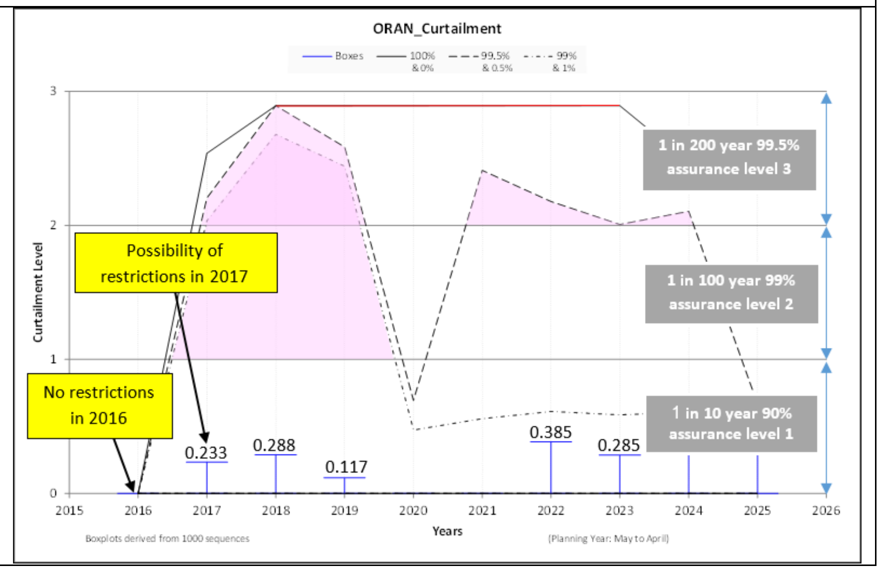
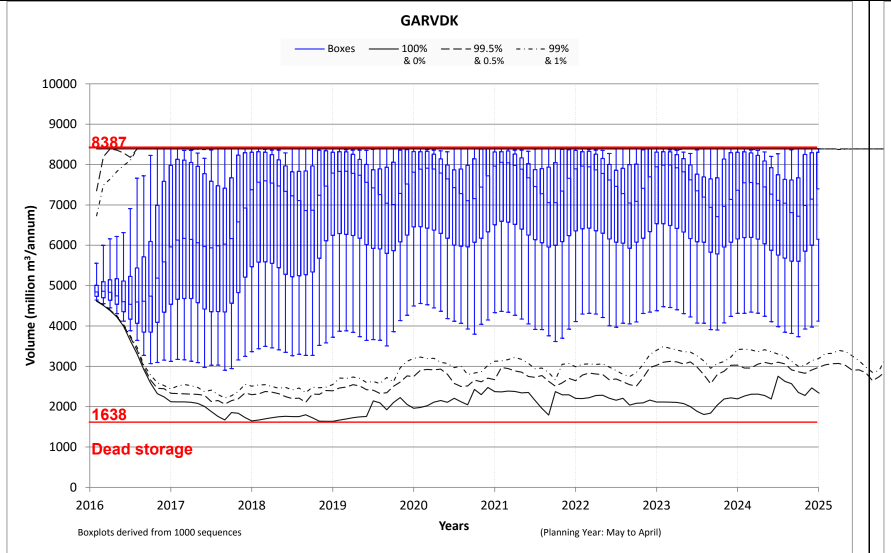
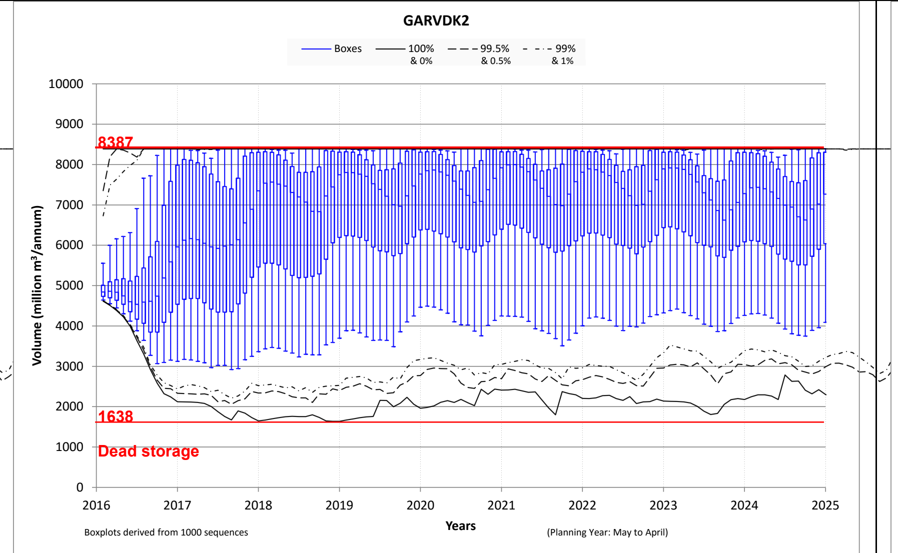
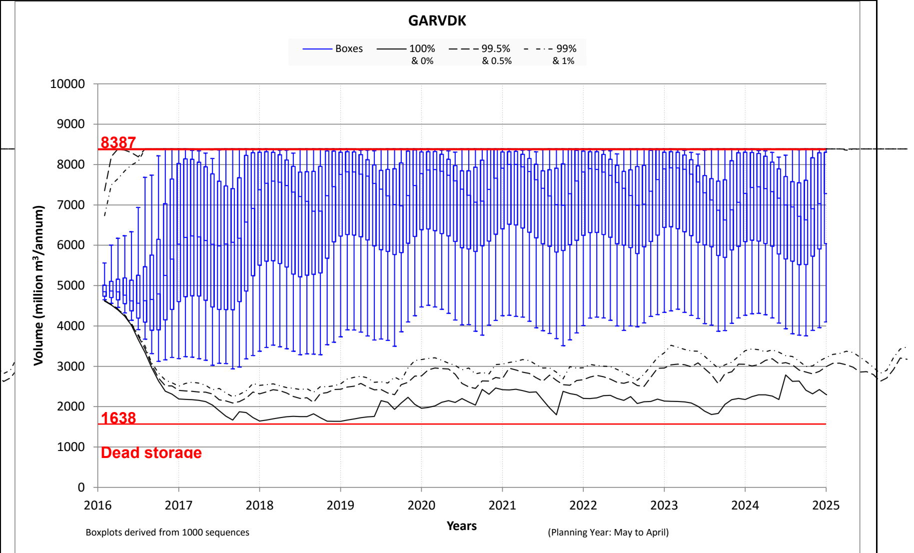
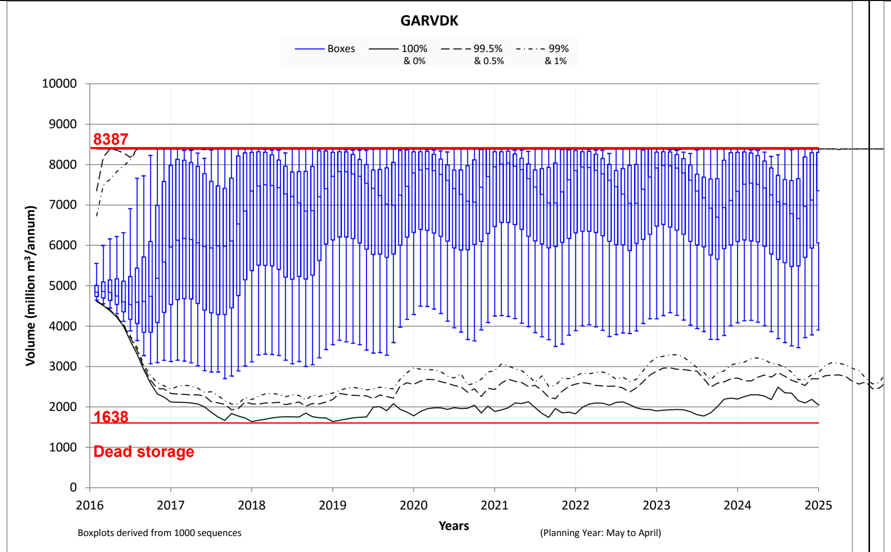
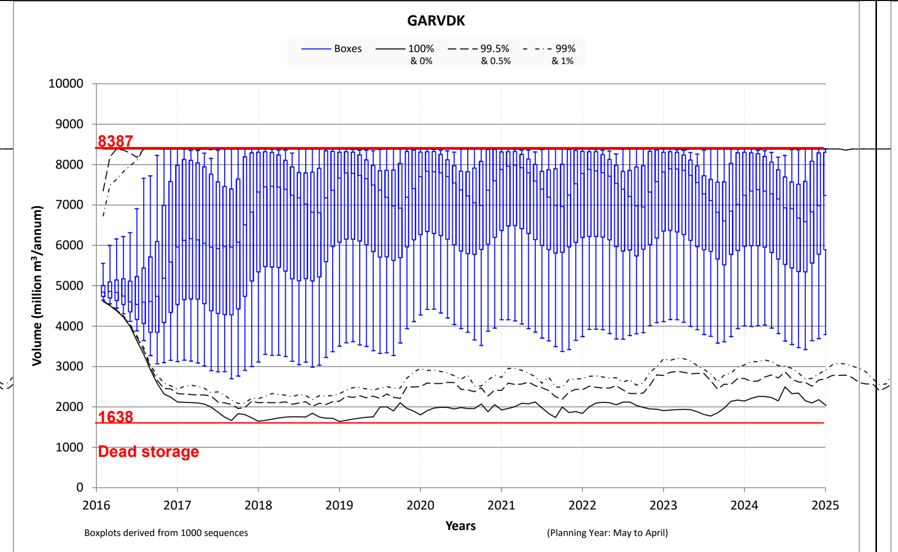
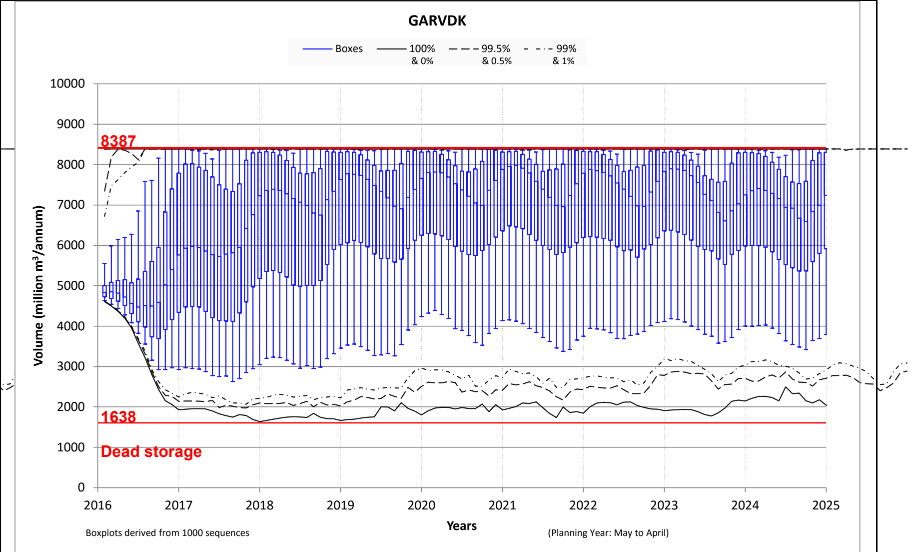
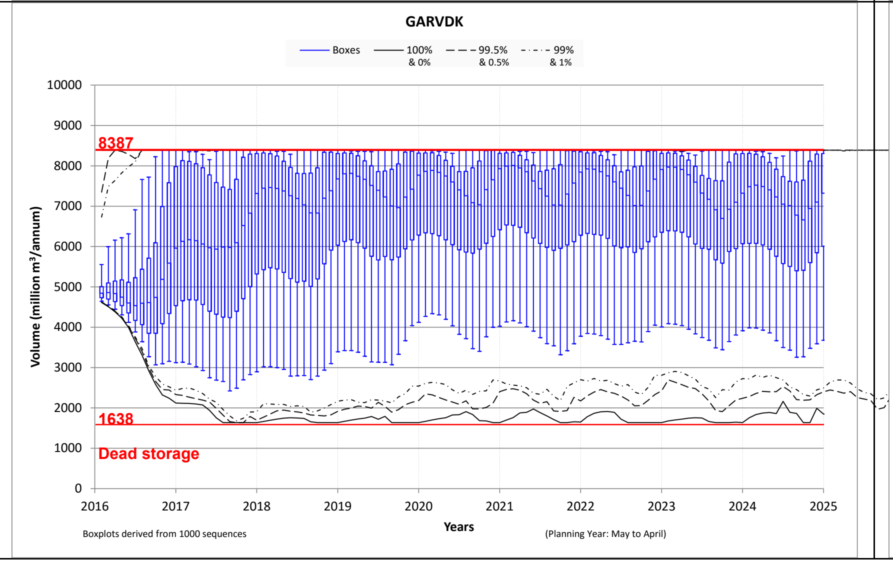
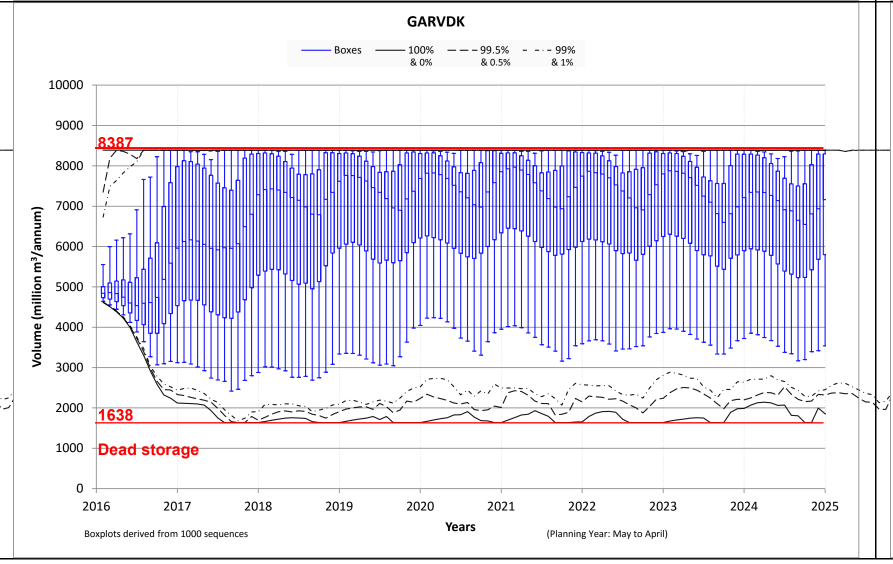
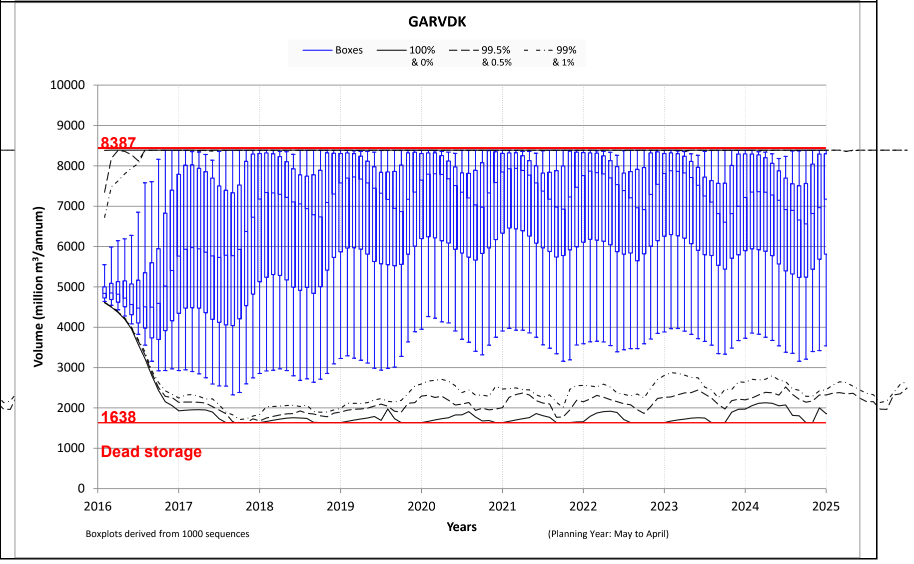
<td></td>
<td></td>
<td></td></tr>
</table>

Table 98: Storage plots of the Orange River over a 10-year period

User Priority	Scenario 1	Scenario 2	Scenario 3
Original			
A			
B			

6.1.2 Socio-economic impacts

In the following section, the present value for each of the socio-economic indicators per scenario analysed are summarised and illustrated graphically as result of the execution of the ASM. A 1000 simulated values were generated for each economic indicator over a period of 10 years and discounted at 0%, 6% and 8% respectively. The main comparison among the results focuses on the present values discounted at 0%. A probability distribution table was used (see Table 99 as example) to summarise the 1000 simulated values for ease of interpretation and a risk-weighted result (average) was obtained for each economic indicator. The summary tables and box-and-whisker plots for each scenario analysed are presented below.

Table 99: Orange River: Scenario 1 (CDL)

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	55 981	43 457	40 387	545 230	397 221	367 656	23 655	18 366	17 071
1	44 209	34 189	31432	433 368	320 564	297 736	19 092	14 372	13 296
5	28 519	20 970	19 334	294 413	211 992	192 175	12 058	8 814	8 094
10	20 647	14 529	13 055	221485	154 696	140 779	8 689	6 077	5 475
15	16 049	11 749	10 655	176 069	125 179	112 765	6 678	4 924	4 461
20	12 602	9 233	8 502	143 535	103 564	94 465	5 240	3 860	3 555
30	9 097	6 398	5 579	107 364	74 724	67 508	3 778	2 658	2 315
40	5 982	4 094	3 775	81355	56 994	50 891	2 471	1696	1560
50	3 652	2 389	2 114	60 052	42 232	37 357	1507	984	872
60	1615	1079	943	34 101	24 249	21842	664	444	388
70	399	261	231	22 909	14 903	12 763	163	107	95
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	7 430	5 326	4 816	86 843	61540	55 444	3 109	2 230	2 017

Table 100: Orange River: Scenario 2 (Base)

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	VIM Metric A (PV) values:			VIM Metric B (PV) values:			VIM Metric C (PV) values:		
0.1	58 868	45 052	41 810	575 876	412 208	377 178	24 863	19 040	17 673
1	46 906	36 219	32 762	467 316	333 832	305 856	19 809	15 228	13 773
5	31 290	23 086	20 902	327 005	233 379	208 275	13 143	9 674	8 821
10	23 212	16 380	14 752	246 625	173 117	157 289	9 737	6 899	6 177
15	17 935	12 940	11 781	201 752	140 189	125 430	7 515	5 424	4 952
20	14 743	10 616	9 709	169 482	118 194	106 653	6 160	4 460	4 070
30	11 085	7 617	6 868	132 023	89 355	80 332	4 640	3 167	2 875
40	8 153	5 398	4 830	104 187	70 973	62 931	3 388	2 238	2 002
50	5 436	3 628	3 152	80 544	54 987	48 145	2 251	1 500	1 309
60	3 069	2 046	1 779	56 973	38 386	33 723	1 264	842	734
70	1 572	1 045	925	34 998	24 050	20 864	646	429	380
80	323	222	191	22 434	13 465	11 356	132	91	78
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	8 939	6 309	5 677	105 833	73 810	66 155	3 738	2 640	2 375

Table 101: Orange River: Scenario 3 (C)

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	60 965	46 505	43 241	610 275	444 439	405 613	25 721	19 630	18 254
1	48 148	37 604	34 042	496 633	361 894	333 453	20 340	15 787	14 355
5	32 766	24 450	22 264	356 761	261 378	235 524	13 738	10 318	9 350
10	24 865	17 946	16 214	277 712	201 022	185 483	10 421	7 552	6 773
15	19 528	14 476	13 303	232 088	169 991	153 542	8 170	6 055	5 570
20	16 310	12 172	11 178	200 301	147 549	135 813	6 789	5 060	4 683
30	12 832	9 287	8 437	163 270	119 250	108 140	5 326	3 856	3 513
40	9 757	7 086	6 328	135 792	100 730	92 060	4 058	2 943	2 615
50	7 152	5 266	4 790	112 429	84 786	77 722	2 954	2 170	1 974
60	4 862	3 690	3 416	88 979	68 585	62 931	1 999	1 518	1 408
70	3 419	2 750	2 601	65 974	53 763	50 364	1 406	1 131	1 070
80	2 115	1 937	1 889	54 722	44 132	41 351	870	797	777
85	1 890	1 783	1 750	32 990	31 123	30 546	778	734	720
90	1 890	1 783	1 750	32 990	31 123	30 546	778	734	720
95	1 890	1 783	1 750	32 990	31 123	30 546	778	734	720
99	1 890	1 783	1 750	32 990	31 123	30 546	778	734	720
99.9	1 890	1 783	1 750	32 990	31 123	30 546	778	734	720
Average:	10 645	7 940	7 283	137 211	103 603	95 448	4 438	3 309	3 035

Table 102: Orange River: Scenario 1a

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	46 922	33 520	31 279	455 993	324 315	295 997	19 748	14 137	13 193
1	38 435	27 797	25 343	364 490	261 847	238 913	16 188	11 699	10 669
5	22 880	17 151	15 714	239 533	172 251	156 114	9 627	7 227	6 586
10	16 341	11 592	10 517	165 568	117 922	107 142	6 807	4 843	4 397
15	11 255	8 966	8 183	133 557	93 634	83 079	4 708	3 791	3 407
20	9 319	7 102	6 272	99 839	75 678	67 369	3 868	2 969	2 640
30	5 710	3 970	3 519	69 184	47 712	42 699	2 366	1 646	1 459
40	2 622	1 747	1 553	45 908	31 010	27 730	1 080	720	640
50	890	581	495	26 890	17 329	14 836	365	238	203
60	-	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	5 185	3 705	3 347	57 965	41 010	36 926	2 171	1 552	1 402

Table 103: Orange River: Scenario 2a

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	50 226	36 058	33 575	479 200	348 061	322 401	21 145	15 187	14 144
1	40 637	29 516	26 870	390 277	280 391	259 736	17 055	12 379	11 268
5	25 089	18 886	16 963	258 572	189 497	169 739	10 564	7 936	7 114
10	18 232	13 119	11 831	196 745	135 389	120 314	7 664	5 485	4 961
15	13 926	9 796	9 018	155 914	107 987	97 165	5 821	4 123	3 779
20	10 974	8 257	7 356	122 888	84 116	76 806	4 621	3 449	3 073
30	7 609	5 176	4 542	91 654	62 412	54 393	3 170	2 145	1 906
40	4 451	3 038	2 629	63 920	44 532	38 833	1 842	1 256	1 086
50	2 259	1 566	1 369	40 557	28 118	24 631	930	645	562
60	655	412	350	24 727	15 407	13 013	268	169	143
70	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	6 318	4 436	3 985	72 010	49 994	44 739	2 643	1 857	1 668

Table 104: Orange River: Scenario 3a

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	50 232	37 017	34 493	488 500	354 443	328 505	21 189	15 595	14 534
1	41 702	30 730	28 043	399 511	292 666	267 844	17 569	12 893	11 772
5	26 284	19 294	17 622	277 589	197 892	177 842	11 017	8 142	7 369
10	19 233	13 920	12 613	201 201	141 247	127 412	8 079	5 822	5 304
15	14 641	10 551	9 716	159 035	115 544	103 315	6 120	4 439	4 082
20	11 616	8 966	8 429	127 593	90 550	80 838	4 873	3 777	3 562
30	7 981	5 589	4 911	93 069	65 639	58 705	3 314	2 341	2 055
40	5 033	3 350	2 957	67 493	46 949	41 255	2 078	1 382	1 223
50	2 879	1 763	1 514	44 757	31 749	27 637	1 183	725	624
60	850	558	480	26 475	16 871	14 404	348	229	197
70	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	6 674	4 748	4 283	75 244	52 846	47 476	2 793	1 988	1 794

Table 105: Orange River: Scenario 1b

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	43 591	31 577	28 640	426 409	293 149	261 027	19 337	14 069	12 777
1	33 366	24 254	22 123	312 122	232 023	210 207	14 800	10 649	9 712
5	19 947	15 319	13 498	198 546	144 034	127 393	8 611	6 610	5 773
10	12 957	8 574	7 719	137 755	92 278	81 913	5 396	3 645	3 219
15	8 573	5 821	5 183	94 378	66 894	59 636	3 554	2 441	2 178
20	5 341	3 477	3 021	69 874	46 473	41 832	2 217	1 439	1 247
30	2 157	1 449	1 210	37 662	25 710	23 128	885	597	497
40	213	157	134	21 653	13 219	11 085	87	64	55
50	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	3 586	2 519	2 262	40 065	27 995	25 096	1 535	1 081	971

Table 106: Orange River: Scenario 2b

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	46 240	33 381	30 237	445 049	312 435	282 328	20 443	14 821	13 443
1	35 446	26 296	23 728	340 391	240 114	218 746	15 710	11 349	10 327
5	23 015	16 532	14 850	222 110	158 221	142 432	9 910	7 277	6 479
10	14 901	10 451	8 962	155 927	106 834	95 330	6 655	4 362	3 743
15	9 863	7 206	6 170	118 675	80 498	70 241	4 139	2 996	2 572
20	7 400	4 829	4 240	87 877	59 605	52 702	3 076	2 018	1 761
30	3 832	2 431	2 145	57 354	38 370	32 927	1 585	1 005	885
40	1 347	864	769	29 902	20 428	18 273	553	355	315
50	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	4 383	3 031	2 708	49 988	34 364	30 643	1 872	1 297	1 159

Table 107: Orange River: Scenario 3b

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	46 486	32 630	29 557	455 520	316 402	282 741	20 021	14 511	13 163
1	36 626	27 286	25 105	351 157	259 606	236 850	16 332	11 890	10 951
5	22 621	16 411	14 980	229 527	163 847	147 307	9 918	7 300	6 500
10	15 805	11 571	10 302	161 542	112 389	102 913	6 741	4 865	4 280
15	11 081	8 044	7 070	122 858	90 947	80 245	4 625	3 373	2 938
20	7 969	5 429	4 816	97 671	64 064	56 349	3 317	2 259	2 005
30	4 183	2 830	2 456	60 862	40 176	34 449	1 724	1 168	1 016
40	1 530	1 073	926	32 158	23 388	21 520	629	441	381
50	163	145	132	21 313	12 662	10 602	67	59	54
60	-	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	4 656	3 268	2 934	52 697	36 709	32 882	1 993	1 403	1 260

Table 108: Mean present value per economic indicator and scenario

Scenario	GDP loss (R million)			Employment loss (numbers)			Household income loss (R million)		
	0%	**6%**	8%	**0%**	**6%**	8%	**0%**	**6%**	8%
Scenario 1	7 430	5 326	4 816	86 843	61 540	55 444	3 109	2 230	2017
Scenario 2	8 939	6 309	5 677	105 833	73 810	66 155	3 738	2 640	2 375
Scenario 3	10 645	7 940	7 283	137 211	103 603	95 448	4 438	3 309	3 035
Scenario 1a	5 185	3 705	3 347	57 965	41 101	36 926	2 171	1 552	1 402
Scenario 2a	6 318	4 436	3 985	72 010	49 994	44 739	2 643	1 857	1 668
Scenario 3a	6 674	4 748	4 283	75 244	52 846	47 476	2 793	1 988	1 794
Scenario 1b	3 586	2 519	2 262	40 065	27 995	25 096	1 535	1 081	971
Scenario 2b	4 383	3 031	2 708	49 988	34 364	30 643	1 872	1 297	1 159
Scenario 3b	4 656	3 268	2 934	52 697	36 709	32 882	1 993	1 403	1 260

Table 109: Present values of GDP loss at 0%, 6% and 8%

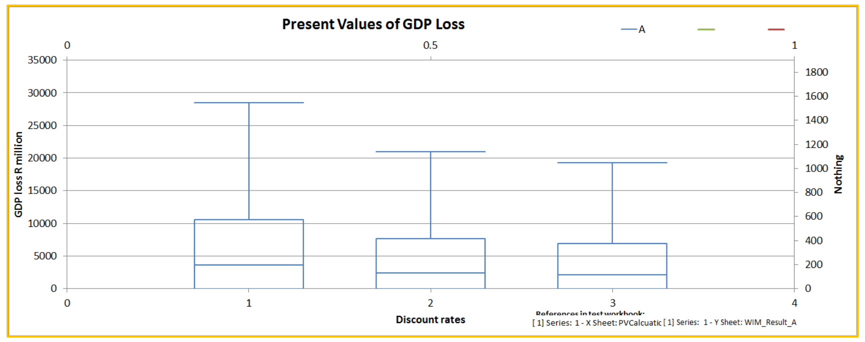
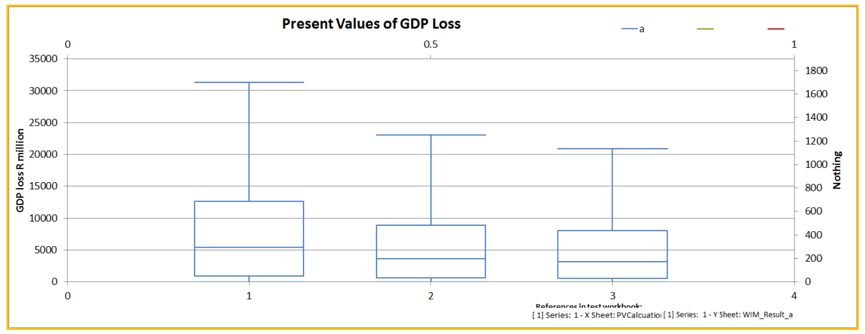
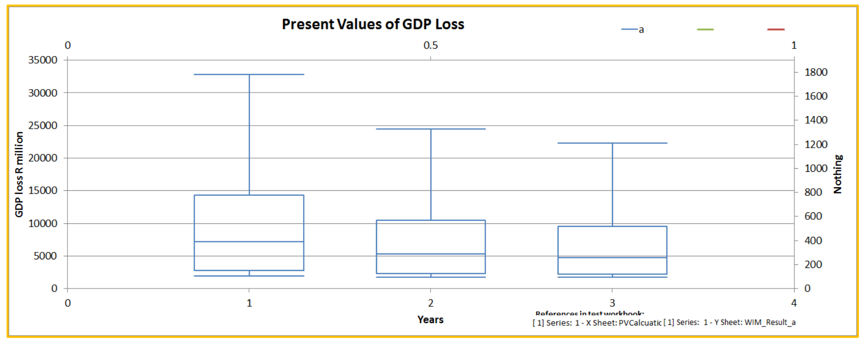
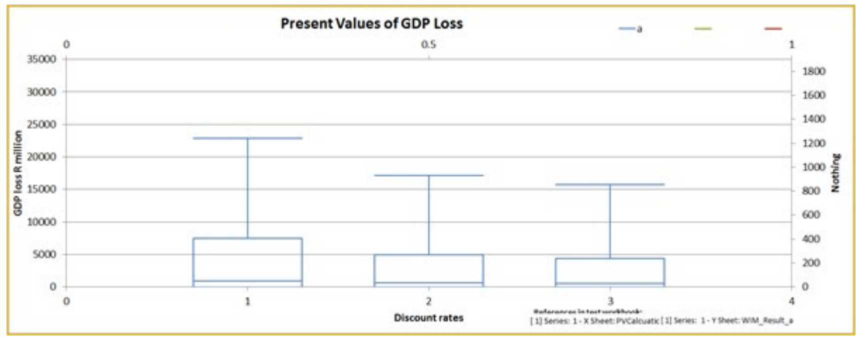
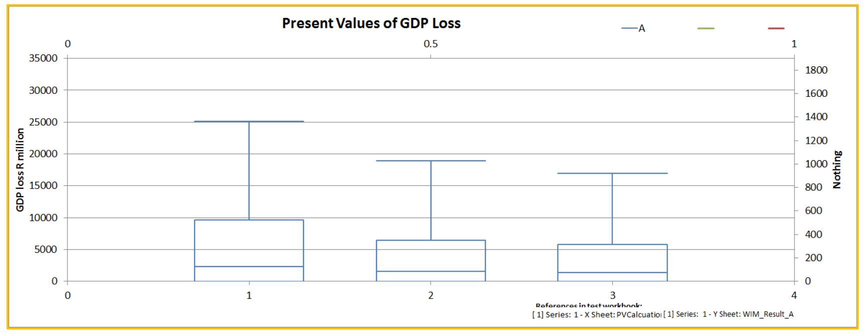
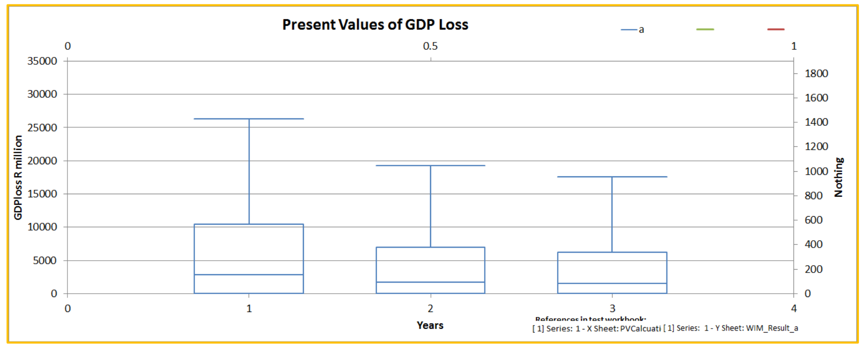
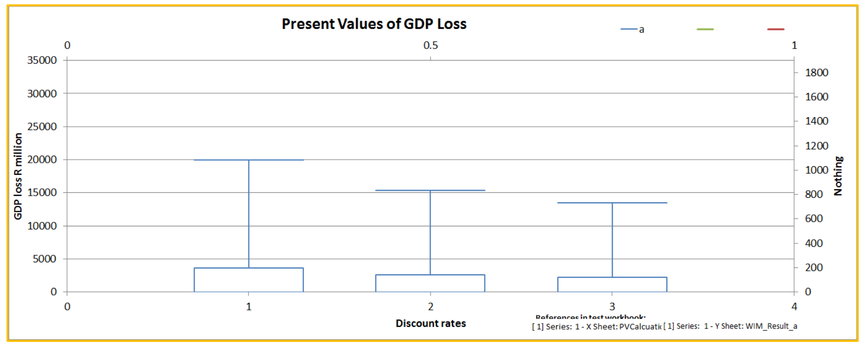
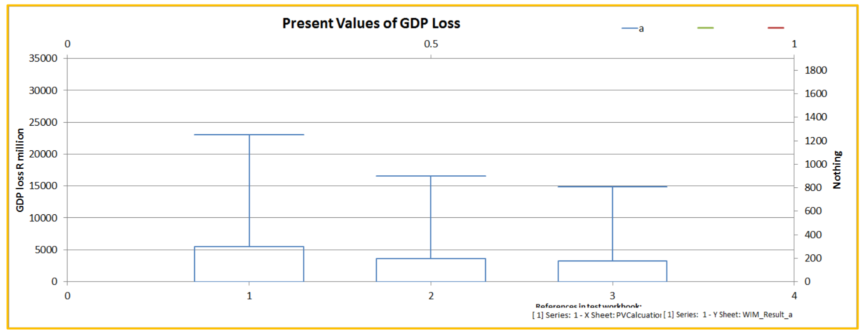
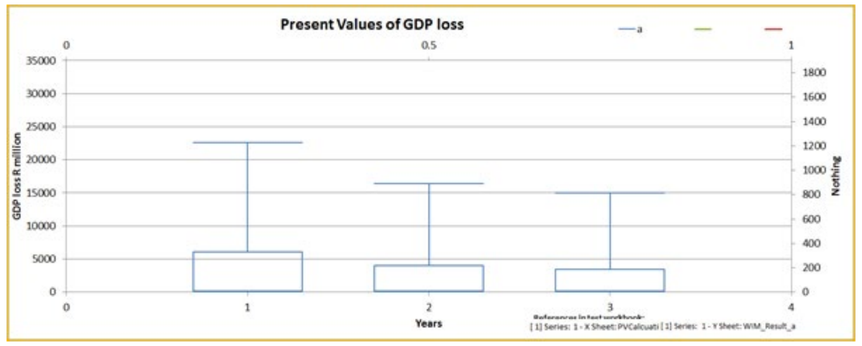
User Priority	Scenario 1	Scenario 2	Scenario 3
Original			
A			
B			

Table 110: Present values of employment loss

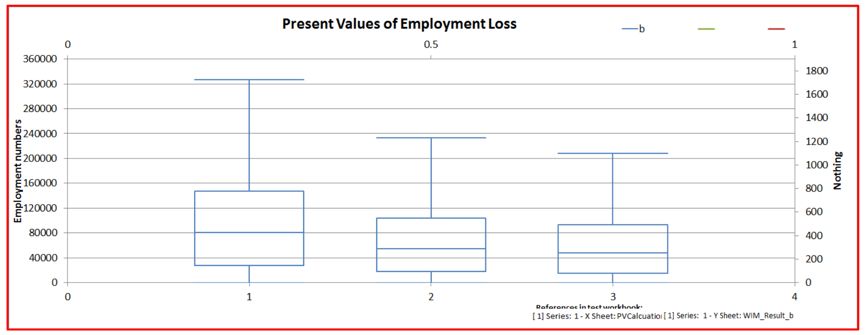
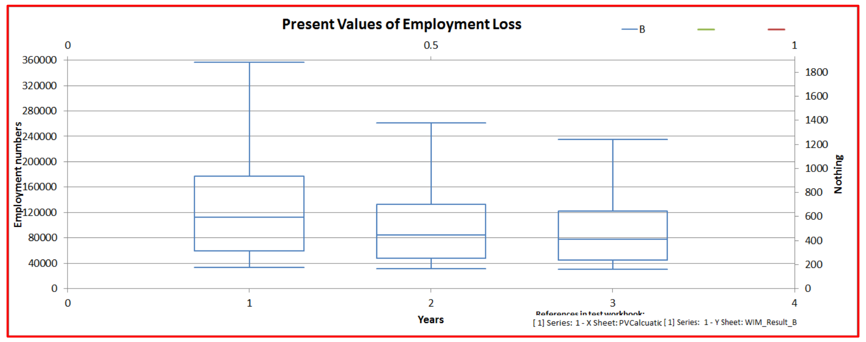
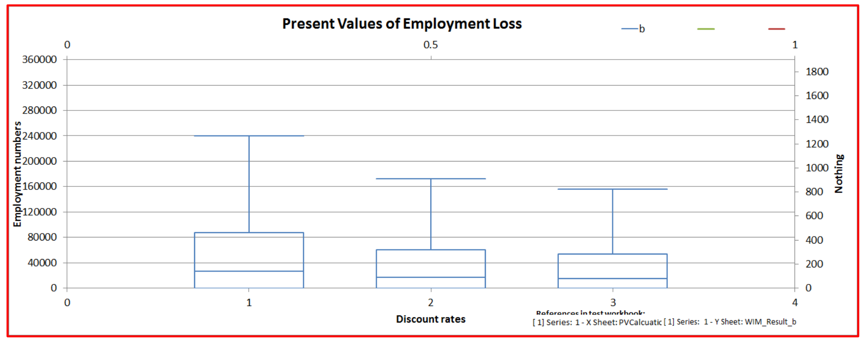
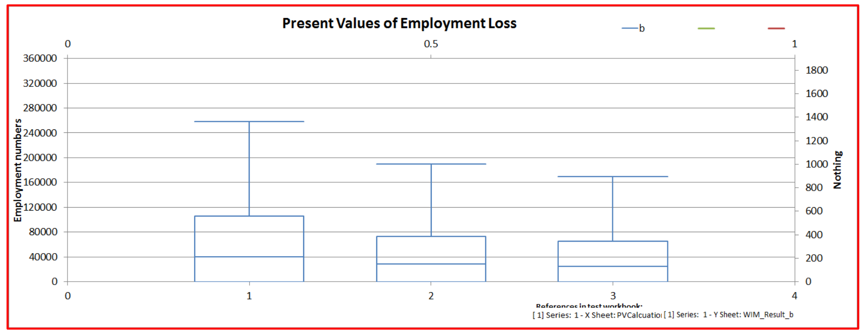
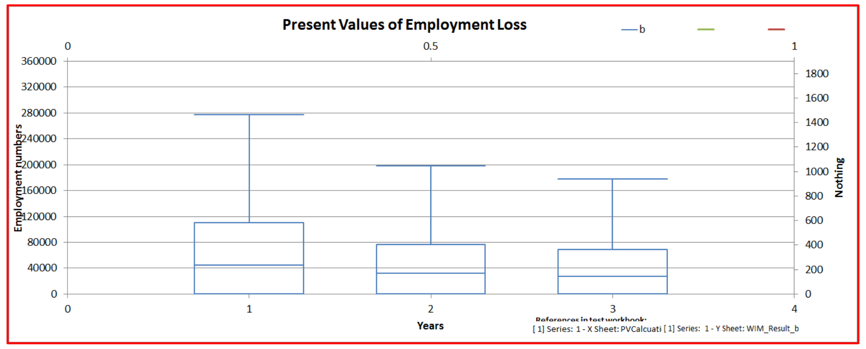
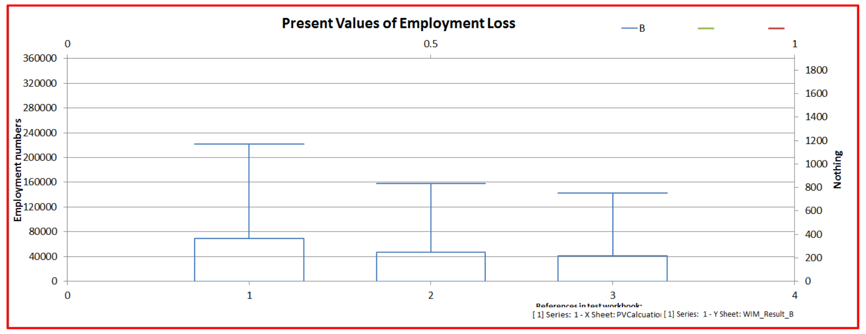
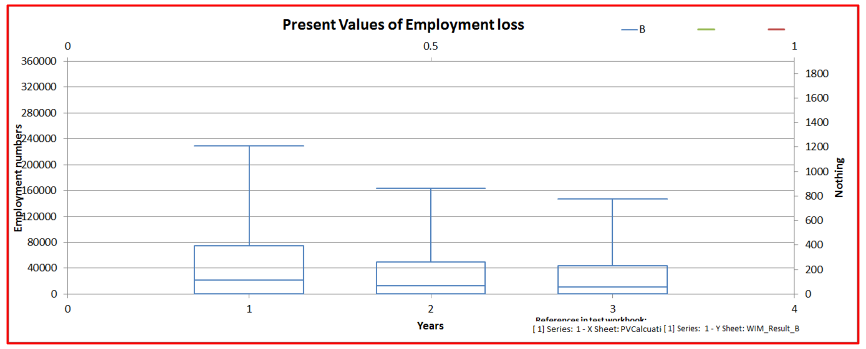
User Priority	Scenario 1	Scenario 2	Scenario 3
Original			
A			
B			

Table 111: Present values of household income loss

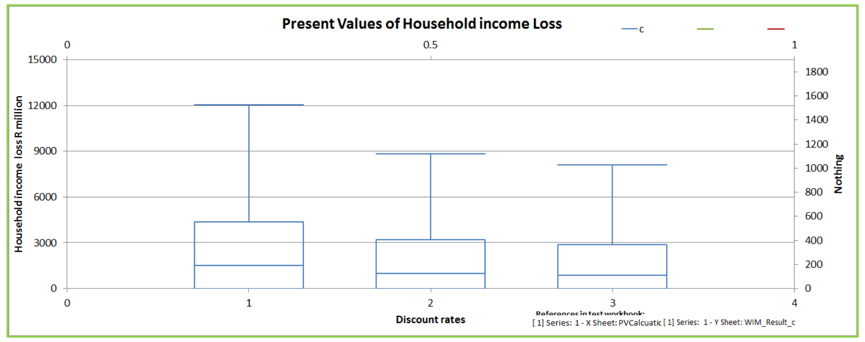
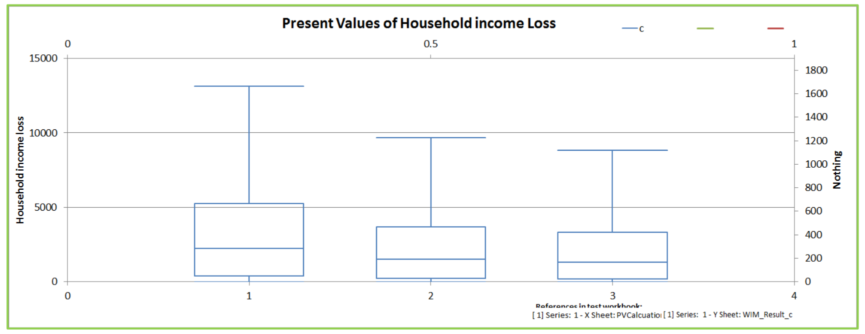
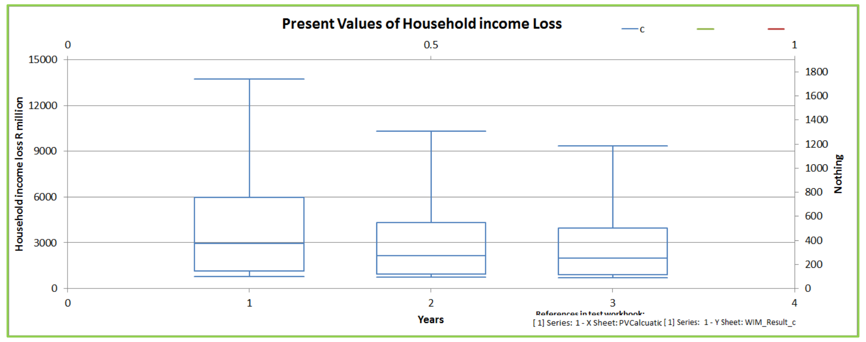
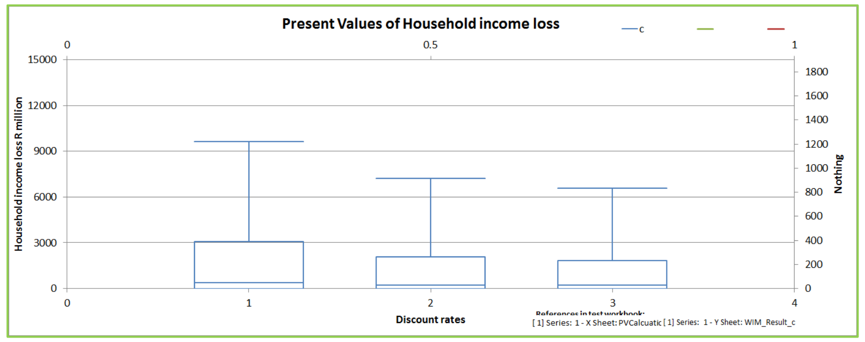
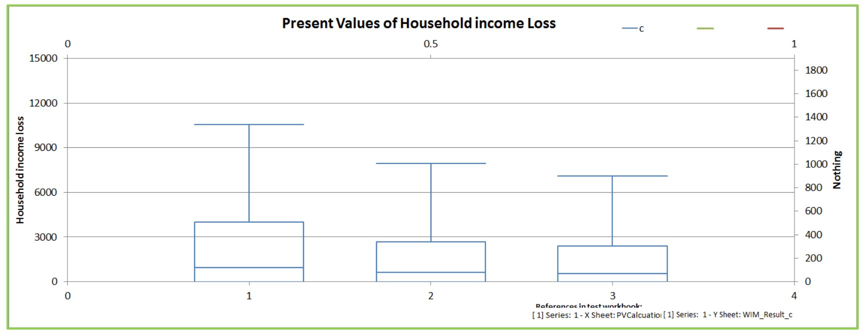
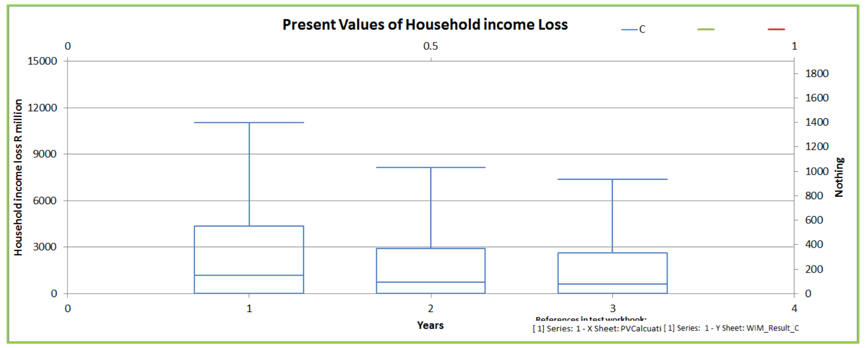
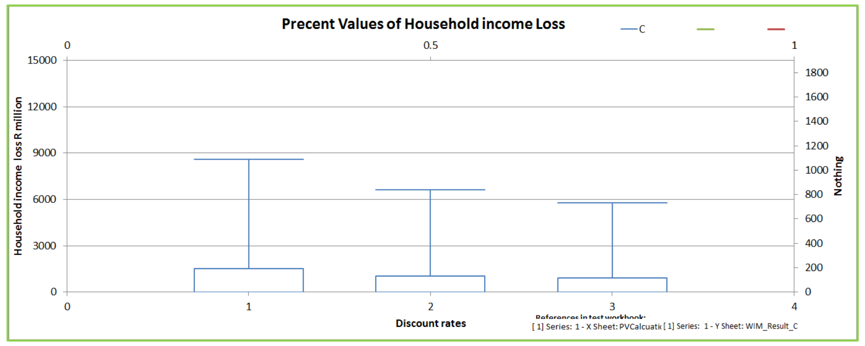
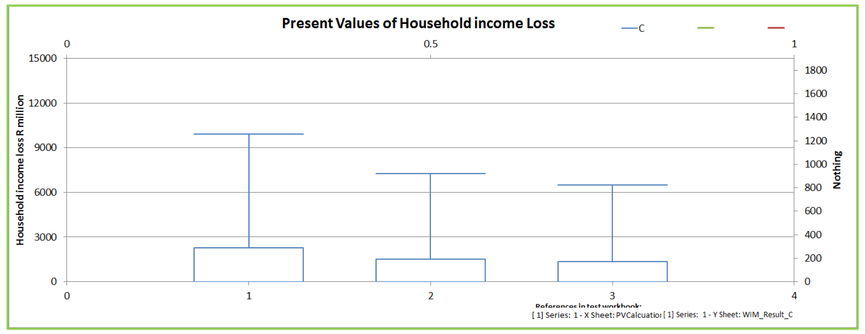
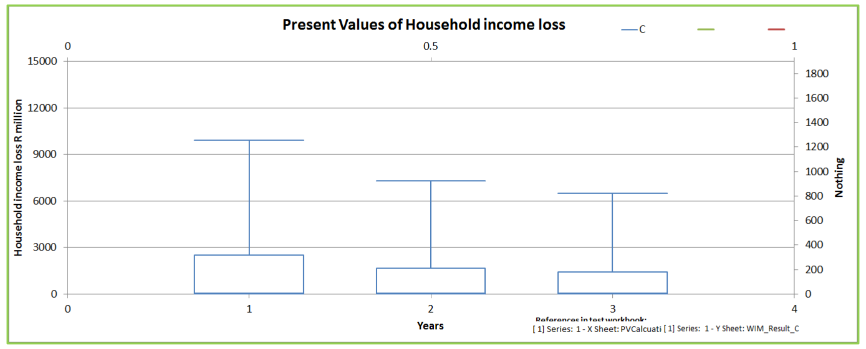
User Priority	Scenario 1	Scenario 2	Scenario 3
Original			
A			
B			

Table 112: Annual values of GDP loss at 0%, 6% and 8%

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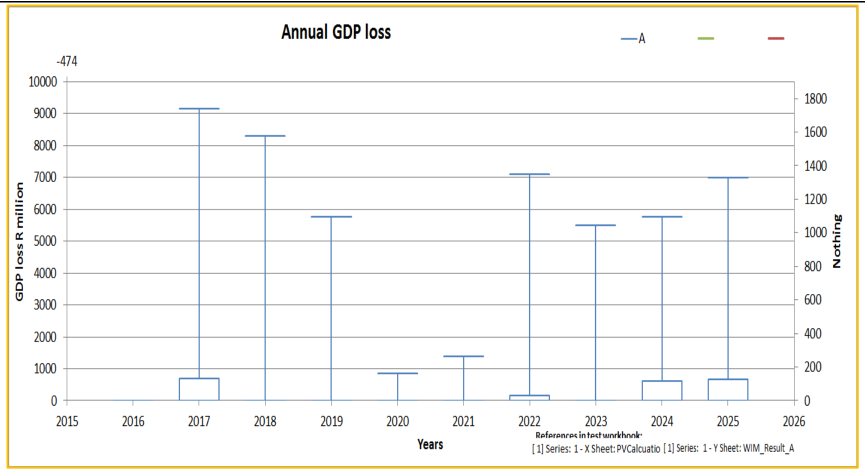
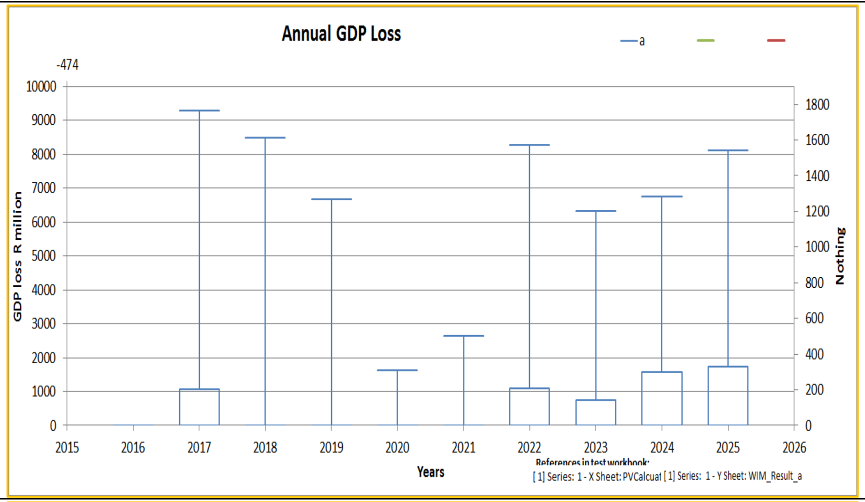
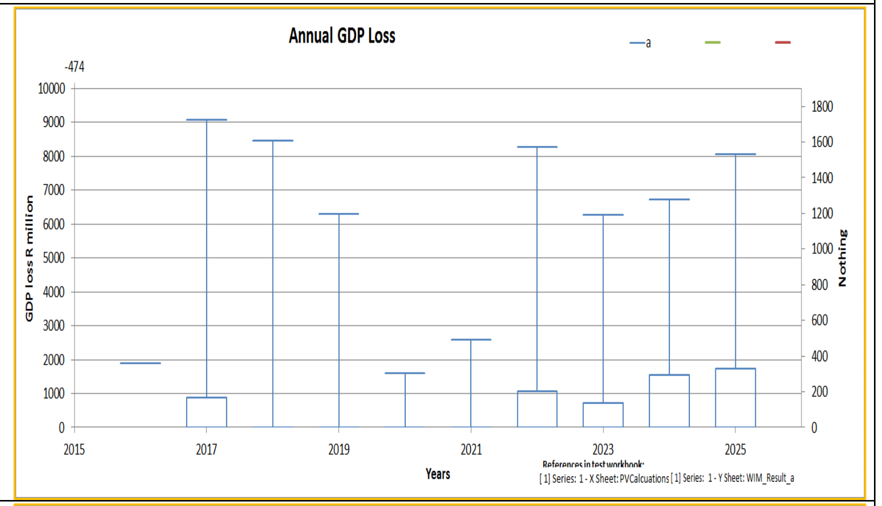
<tr><td>Original</td><td>
</td><td>
</td><td>
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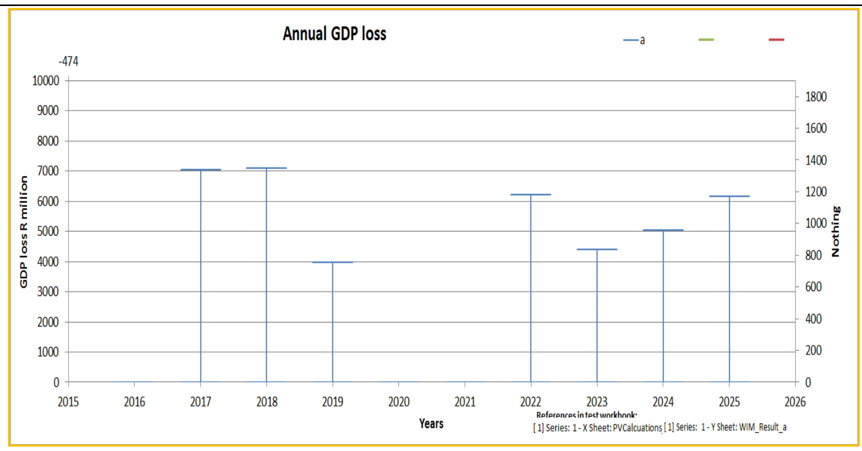
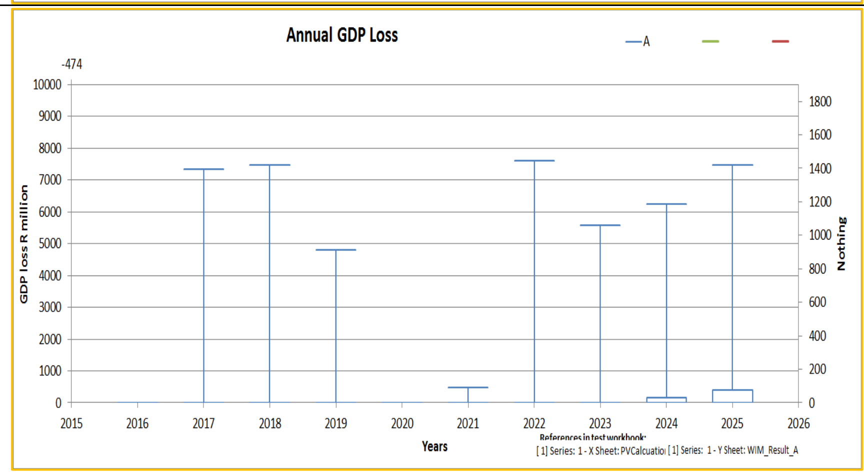
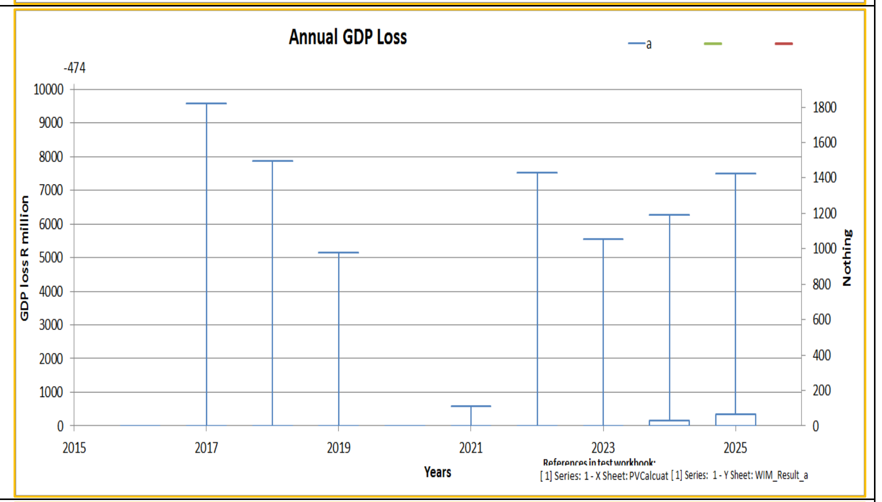
<tr><td>A</td><td>
</td><td>
</td><td>
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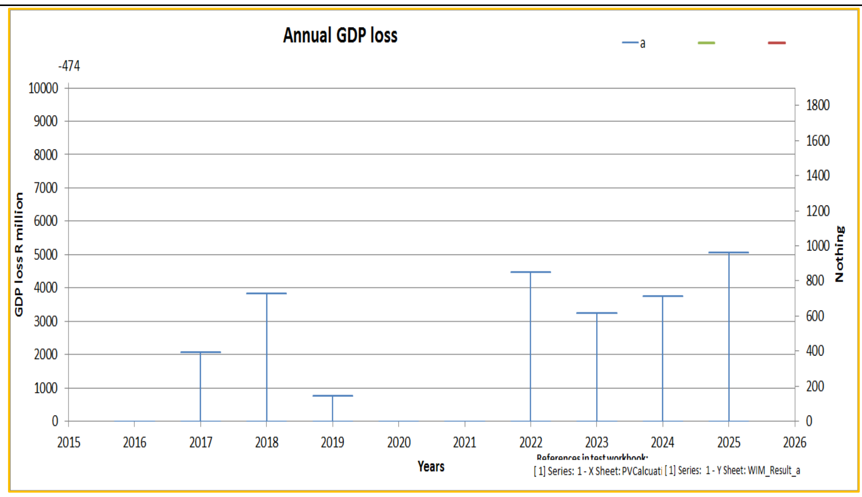
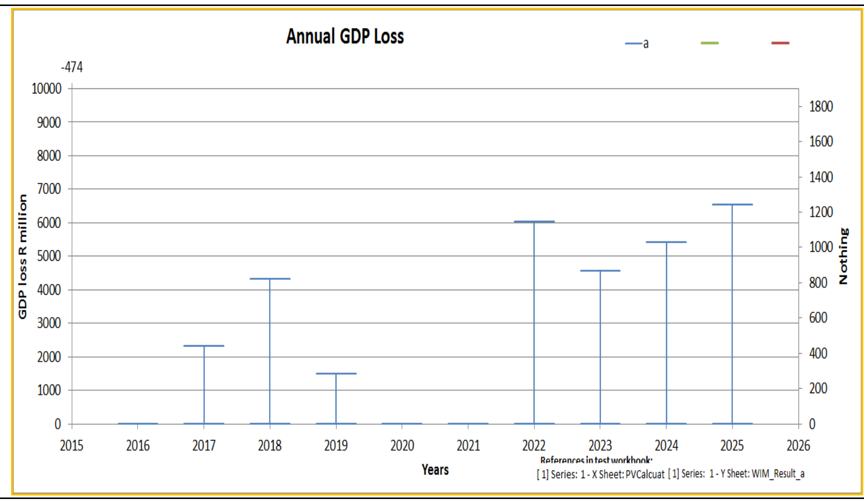
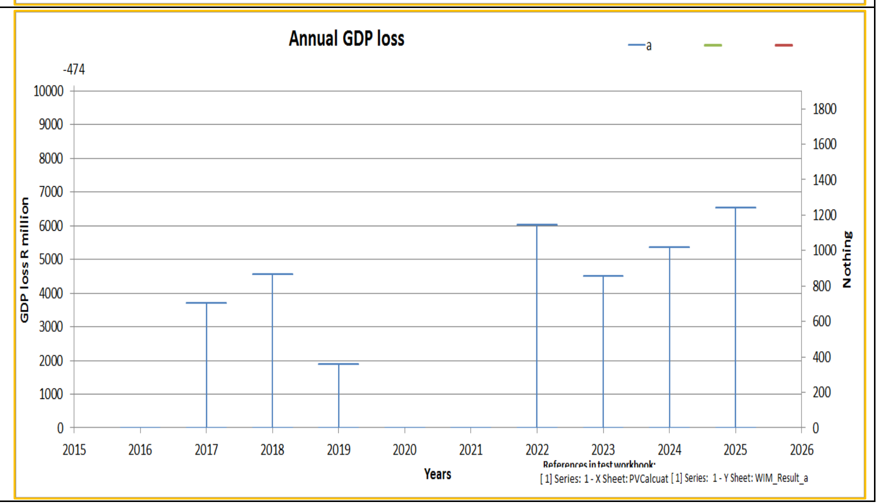
<tr><td>B</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 113: Annual values of employment loss

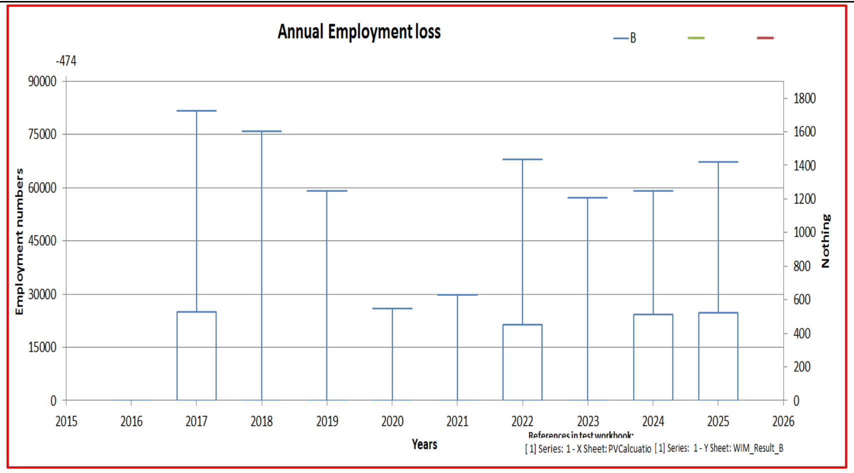
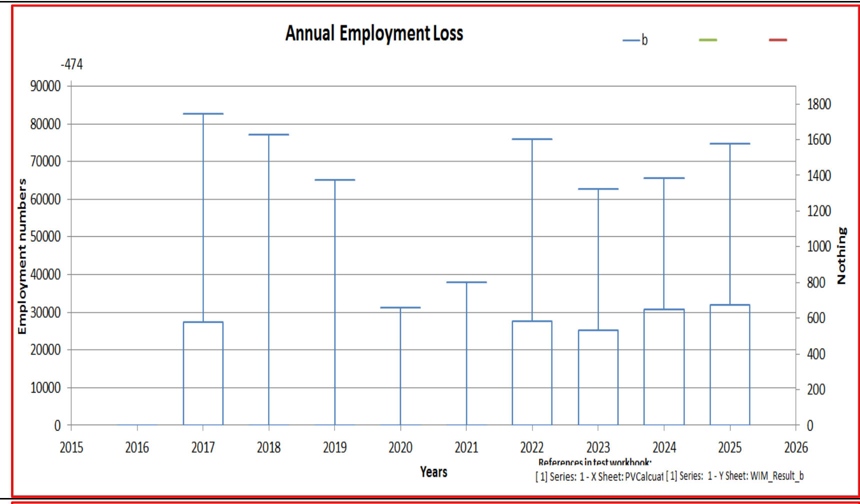
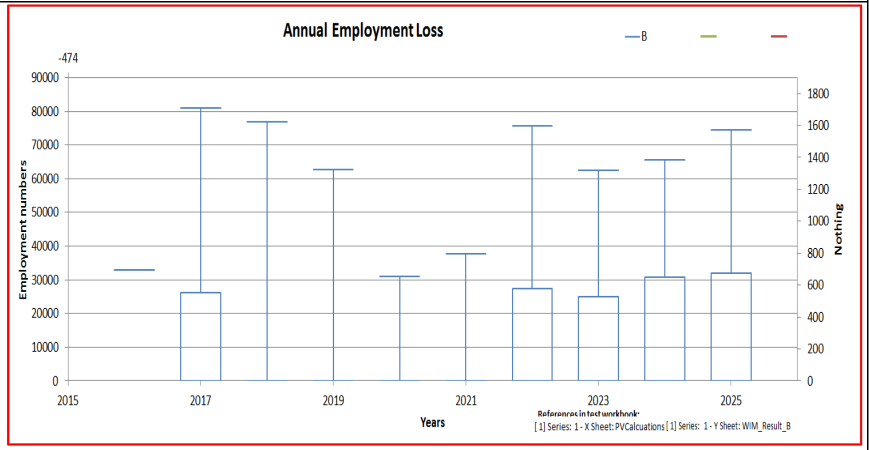
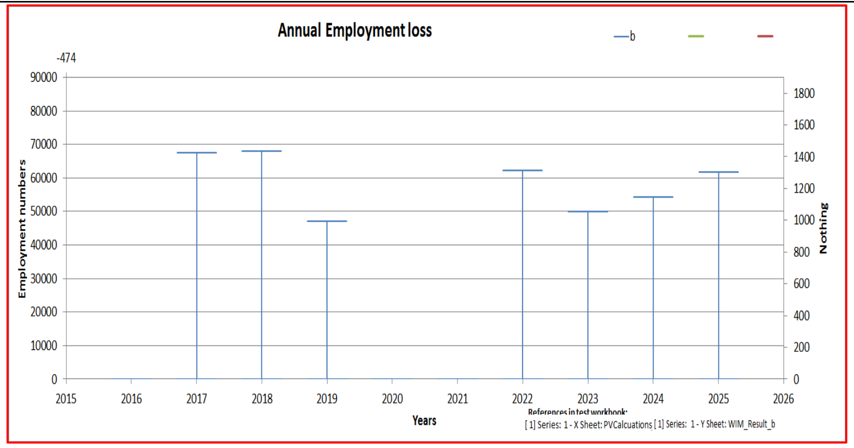
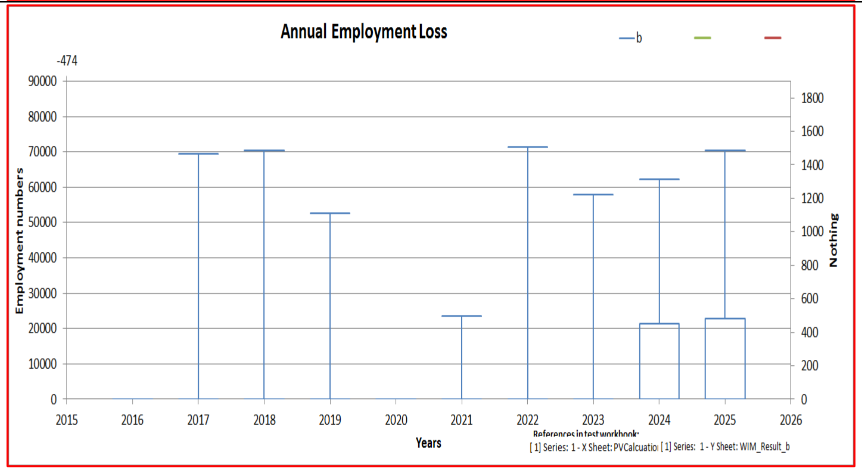
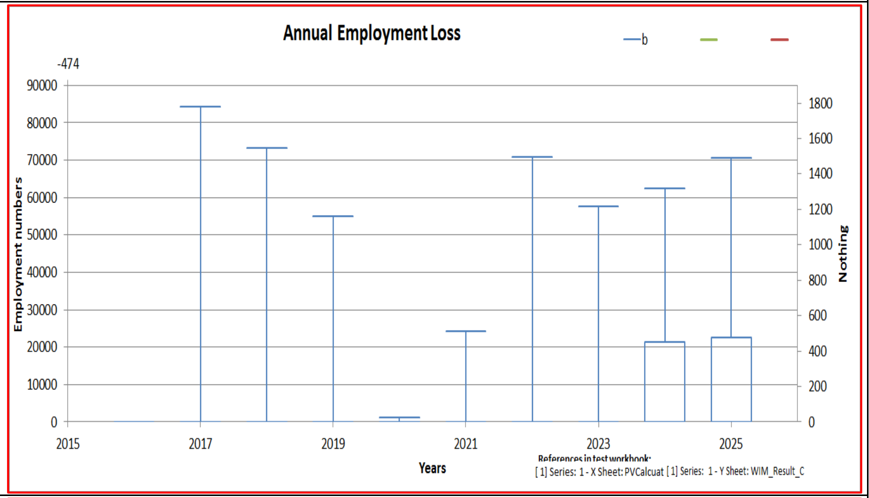
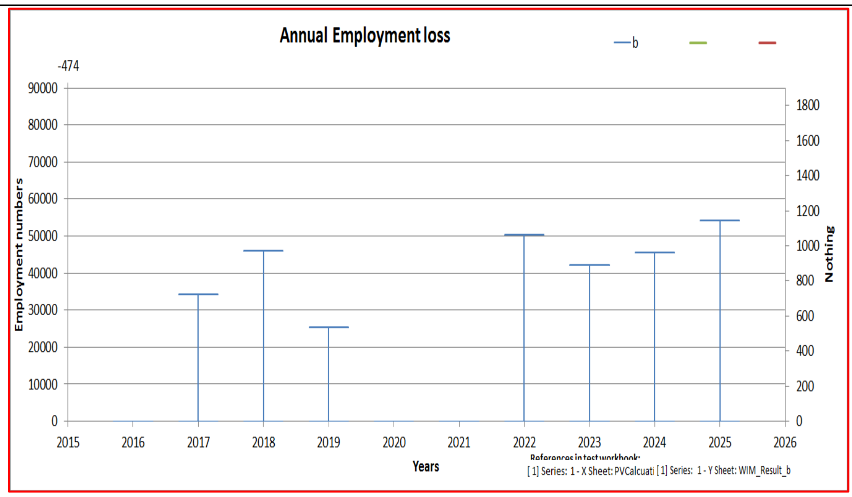
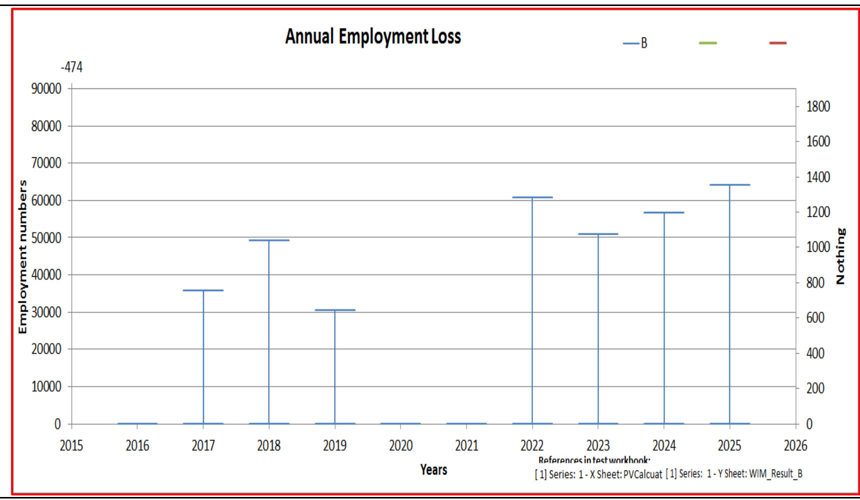
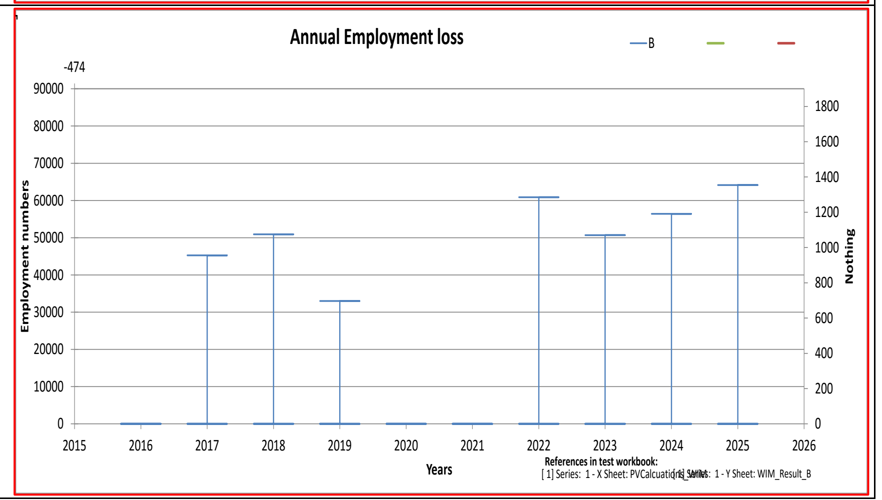
User Priority	Scenario 1	Scenario 2	Scenario 3
Original			
A			
B			

Table 114: Annual values of household income loss

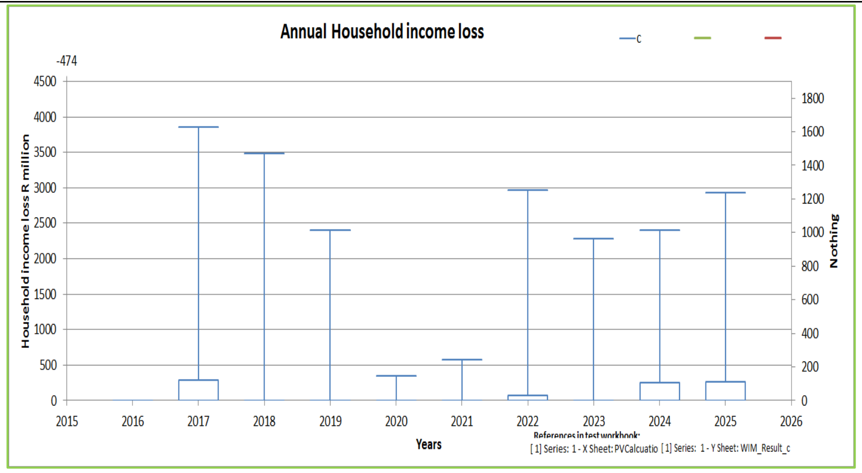
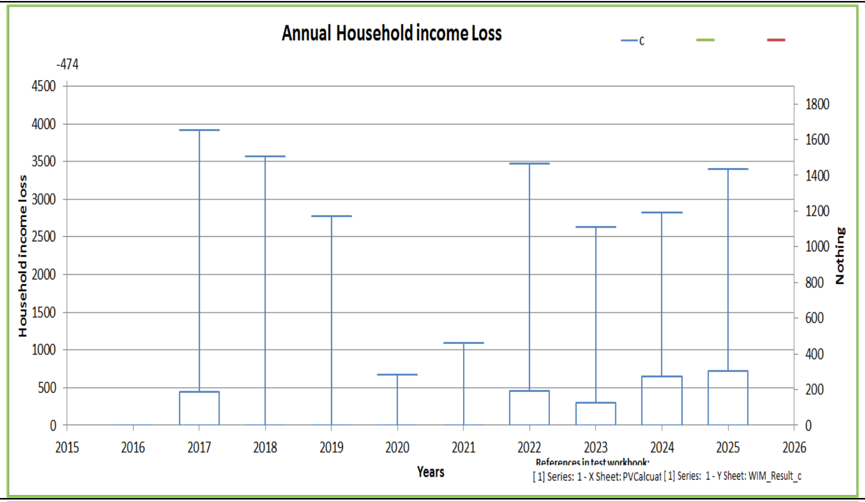
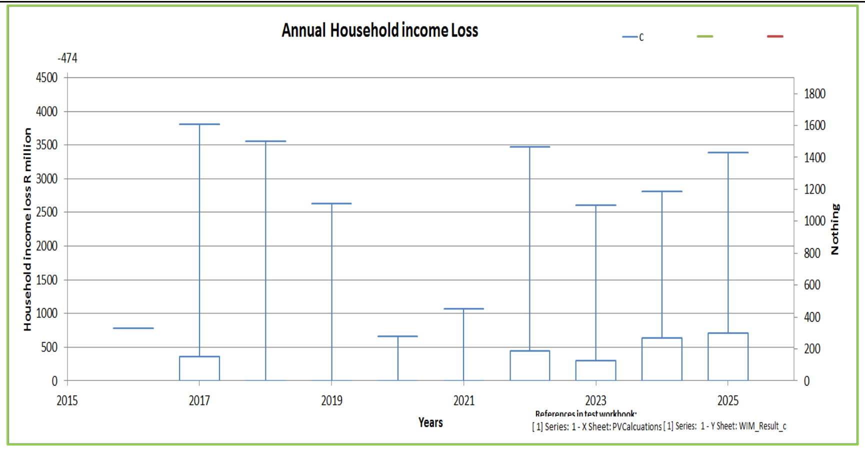
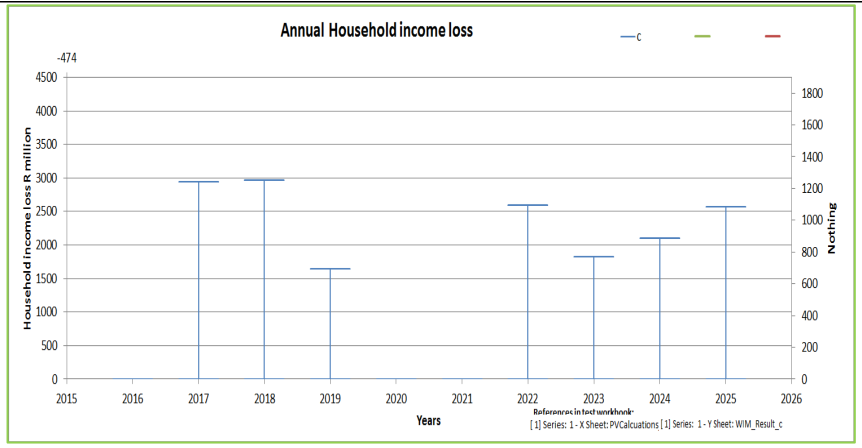
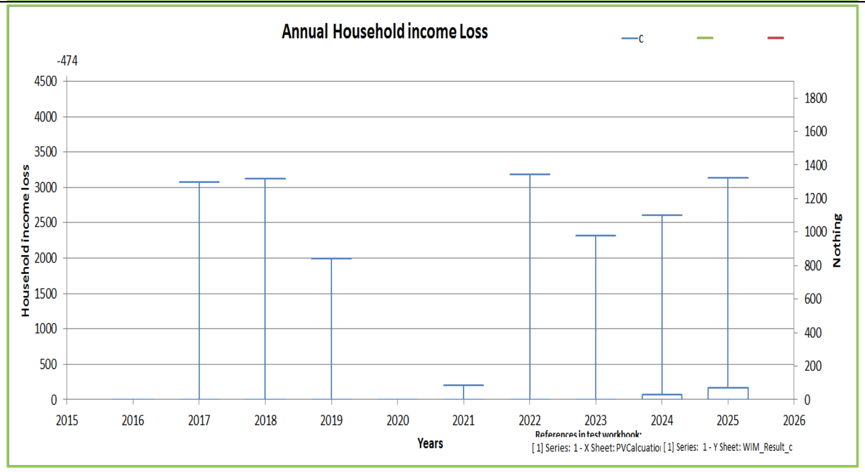
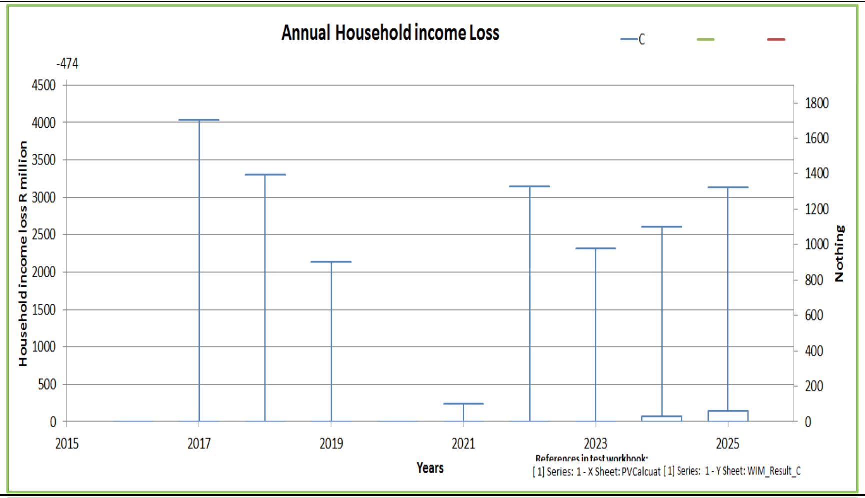
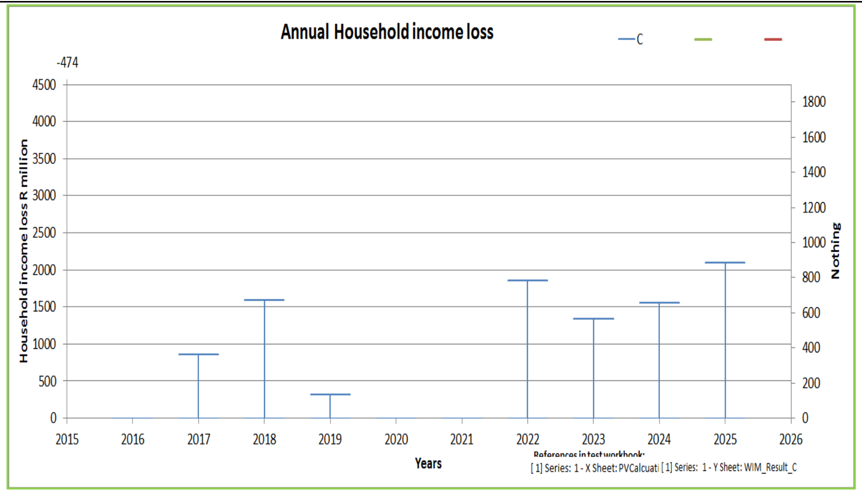
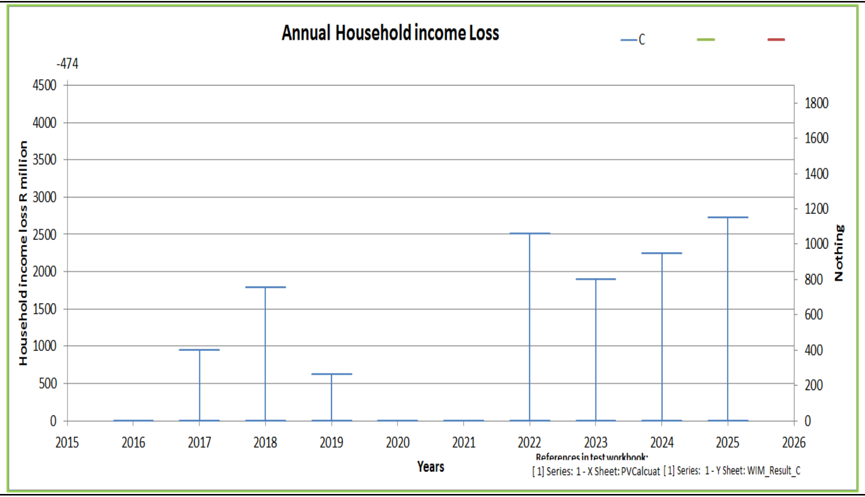
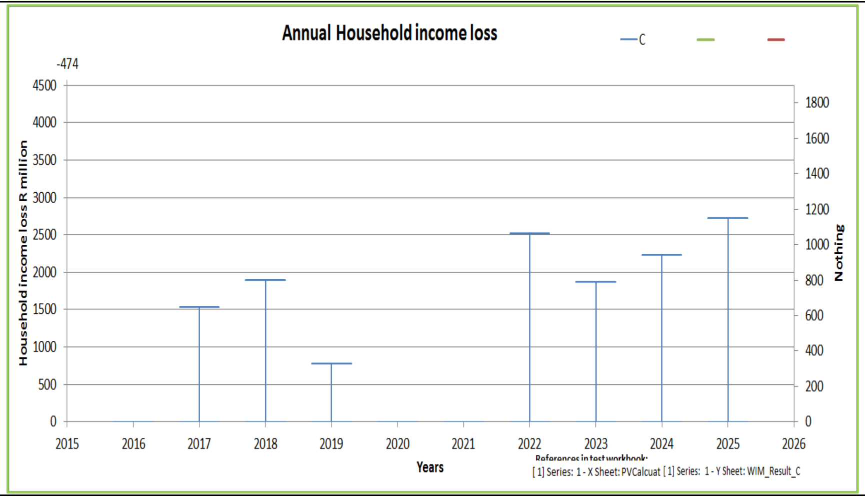
User Priority	Scenario 1	Scenario 2	Scenario 3
Original			
A			
B			

Table 115 lists the results of the scenario analyses undertaken for the Orange River System as a matrix between the scenarios analysed, the average present value, and the annual average of the three economic indicators. Table 115 shows that for the scenarios where the second alternative (Option B) user priority classification was applied, the economic impact in terms of loss in GDP as well as loss in household income and a reduction in employment numbers were less than for the original and first alternative user priority classifications.

Table 115: Orange River System scenario-economic indicators matrix (present value and annual averages)

Scenario	GDP loss (R million m³)		Employment loss numbers		Household income loss (R million m³)	
	Present value	Annual	present value	Annual	Present value	Annual
Scenario 1	7 430	743	66 843	8 684	3 109	311
Scenario 2	8 939	894	105 833	10 583	3 738	374
Scenario 3	10 645	1 065	137 211	13 721	4 438	444
Scenario 1a	5 185	519	57 965	5 797	2 171	217
Scenario 2a	6 318	632	72 010	7 201	2 643	264
Scenario 3a	6 674	667	75 244	7 524	2 793	279
Scenario 1b	3 586	359	40 065	4 006	1 535	154
Scenario 2b	4 383	438	49 988	4 999	1 872	187
Scenario 3b	4 656	466	52 697	5 270	1 993	199

Water resource managers and system analysists have been contemplating that the irrigation sector in the Orange River System was prioritised at a too high assurance of water supply. In the original priority classification criteria, 50% of the water supply to the irrigation sector was at an assurance of 99.5% (risk of failure 1 in 200 years). For the first alternative user priority classification (Option A), it was decided to distinguish between permanent and temporary crops in the irrigation sector. This split can be interpreted as 30% and 70% of the demand at an assurance of water supply of 99% and 90% respectively. Reasonable results were produced for the Option A scenario analyses in terms of the system storage as well as the system curtailments and subsequently economic impact.

The second alternative user priority classification (Option B) entailed prioritising 100% of the irrigation sector at a low assurance of water supply of 90% (risk of failure 1 in 10 years). Even though the economic results seem more favourable than other options, the probability of the storage volume of the combined Gariep and Vanderkloof dams to reduce to dead storage capacity is encountered too frequently. This is comprehensible considering the large volume of the water demand on the Orange River System required by the irrigation sector. It also emphasises the importance of assessing water supply curtailment criteria regionally.

6.1.3 Farm producer viability

Table 116 represents the farm producer viability results with a proposed 15% curtailment throughout the Orange River area.

Table 116: Viability Results for the Orange River Project

Water Supply: 15% Curtailment		(30% | 3.3%)			Small-Scale Management Compensation Curtailed (30%,25%,35%|3.3%)						Real Yield Curtailment (2.5%, 5.0%| 30%)						(35% | 5%)		
Description		Option 1: Most Likely			Option 2			Option 3			Option 4			Option 5			Option 6: Extreme		
A) Management Compensation Deduct (%)		0%		30%	0%		25%	0%		35%	0%		30%	0%		30%	0%		35%
B) Return On Capital: Real Yield Rate (%)		3.32%									2.50%			5.0%					
Economical Scale		L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S
Number of Unviable Crops		-	-	-	-	-	-	-	-	2	-	-	-	-	2	2	-	2	3
Unviable Crop Name										Soya Beans, Dry Beans					Dry Beans, Wheat	Soya Beans, Dry Beans		Dry Beans, Wheat	Soya Beans, Dry Beans, Wheat
Short term	Maize	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Soya Beans	-	-	-	-	-	-	-	-	X	-	-	-	-	-	X	-	-	X
	Dry Beans	-	-	-	-	-	-	-	-	X	-	-	-	-	X	X	-	X	X
	Potatoes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Summer Vegetables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Winter Vegetables	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Wheat	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	X	X
MT	Lucerne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Long term	Grapes – Fresh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Grapes – Wine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Grapes – Dry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Citrus – Oranges	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Palm Dates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Main points from the analysis are:

- Only short-term crops are affected when the economic scenarios are included.
- Dry beans is the prominent crop, which was evident in all the unviable results.
- Medium-scale farmers were unviable in Option 5, but small-scale farmers remained viable due to a standardised reduced managerial fee for small-scale farmers.

Table 116 and Table 117 indicate the feasibility for crop production in the Orange River System at 10% and 30% water supply curtailments for different farm unit sizes. The farm nett income reduces as the water supply curtailment to the system increases; however, larger farms tend to be affected the least.

Table 117: Feasibility of crop production in the Orange River at 10% curtailment

Note: If Nett Income Negative, Not Feasible to Continue Production				Curtailment 10%; Nett Income (R million)					
				Option 1:	Option 2	Option 3	Option 4	Option 5	Option 6:
	Crop	**Farm Unit Size**	**Farm Size (Ha)**	**30% Fee, 3.3% Real Yield**	**25% Fee, 3.3% Real Yield**	**35% Fee, 3.3% Real Yield**	**30% Fee, 2.5% Real Yield**	**30% Fee, 5% Real Yield**	**35% Fee, 5% Real Yield**
Short term	Maize	Large	250	R1.31	R1.31	R1.31	R1.46	R1.01	R1.01
		Medium	150	R0.60	R0.60	R0.60	R0.69	R0.42	R0.42
		Small	35	R0.11	R0.13	R0.08	R0.13	R0.07	R0.04
	Soya Beans	Large	150	R0.52	R0.52	R0.52	R0.58	R0.40	R0.40
		Medium	100	R0.19	R0.19	R0.19	R0.23	R0.11	R0.11
		Small	25	R0.02	R0.05	R0.00	R0.03	R0.00	−R0.02
	Dry Beans	Large	150	R0.48	R0.48	R0.48	R0.57	R0.30	R0.30
		Medium	100	R0.16	R0.16	R0.16	R0.22	R0.05	R0.05
		Small	25	R0.02	R0.04	−R0.01	R0.03	−R0.01	−R0.04
	Potatoes	Large	150	R5.39	R5.39	R5.39	R5.50	R5.18	R5.18
		Medium	80	R2.66	R2.66	R2.66	R2.71	R2.55	R2.55
		Small	10	R0.25	R0.27	R0.23	R0.26	R0.24	R0.21
	Summer Vegetables	Large	50	R1.34	R1.34	R1.34	R1.38	R1.25	R1.25
		Medium	30	R0.62	R0.62	R0.62	R0.64	R0.56	R0.56
		Small	6	R0.08	R0.10	R0.05	R0.08	R0.07	R0.04
	Winter Vegetables	Large	50	R2.13	R2.13	R2.13	R2.17	R2.04	R2.04
		Medium	30	R1.09	R1.09	R1.09	R1.11	R1.04	R1.04
		Small	6	R0.17	R0.19	R0.15	R0.18	R0.16	R0.14
	Wheat	Large	170	R0.38	R0.38	R0.38	R0.48	R0.17	R0.17
		Medium	110	R0.08	R0.08	R0.08	R0.14	−R0.06	−R0.06
		Small	40	R0.06	R0.08	R0.04	R0.08	R0.01	−R0.01
Medium term	Lucerne	Large	60	R0.78	R0.78	R0.78	R0.82	R0.70	R0.70
		Medium	30	R0.16	R0.16	R0.16	R0.18	R0.11	R0.11
		Small	20	R0.28	R0.30	R0.25	R0.29	R0.25	R0.22
Long term	Grapes – Fresh	Large	60	R2.56	R2.56	R2.56	R2.64	R2.38	R2.38
		Medium	22	R0.64	R0.64	R0.64	R0.67	R0.58	R0.58
		Small	8	R0.26	R0.29	R0.24	R0.27	R0.24	R0.22
	Grapes – Wine	Large	40	R0.43	R0.43	R0.43	R0.47	R0.33	R0.33
		Medium	28	R0.16	R0.16	R0.16	R0.19	R0.09	R0.09
		Small	10	R0.08	R0.11	R0.06	R0.09	R0.06	R0.04
	Grapes – Dry	Large	40	R0.38	R0.38	R0.38	R0.42	R0.30	R0.30
		Medium	28	R0.13	R0.13	R0.13	R0.15	R0.07	R0.07
		Small	10	R0.07	R0.10	R0.05	R0.08	R0.05	R0.03
	Citrus – Oranges	Large	80	R4.94	R4.94	R4.94	R5.04	R4.75	R4.75
		Medium	40	R2.24	R2.24	R2.24	R2.29	R2.14	R2.14
		Small	15	R0.87	R0.90	R0.85	R0.89	R0.84	R0.81
	Palm Dates	Large	250	R63.45	R63.45	R63.45	R63.75	R62.81	R62.81
		Medium	100	R25.10	R25.10	R25.10	R25.22	R24.84	R24.84
		Small	15	R3.69	R3.72	R3.67	R3.71	R3.66	R3.63

Table 118: Feasibility of crop production in the Orange River at 30% curtailment

Note: If Nett Income Negative, Not Feasible to Continue Production				Curtailment 30%; Nett Income (R million)					
				Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
	Crop	Farm Unit Size	Farm Size (Ha)	30% Fee, 3.3% Real Yield	25% Fee, 3.3% Real Yield	35% Fee, 3.3% Real Yield	30% Fee, 2.5% Real Yield	30% Fee, 5% Real Yield	35% Fee, 5% Real Yield
Short term	Maize	Large	250	R0.68	R0.68	R0.68	R0.83	R0.38	R0.38
		Medium	150	R0.22	R0.22	R0.22	R0.31	R0.04	R0.04
		Small	35	R0.02	R0.04	−R0.00	R0.04	−R0.02	−R0.05
	Soya Beans	Large	150	R0.15	R0.15	R0.15	R0.21	R0.02	R0.02
		Medium	100	−R0.06	−R0.06	−R0.06	−R0.02	−R0.14	−R0.14
		Small	25	−R0.04	−R0.01	−R0.06	−R0.03	−R0.06	−R0.08
	Dry Beans	Large	150	R0.11	R0.11	R0.11	R0.20	−R0.07	−R0.07
		Medium	100	−R0.08	−R0.08	−R0.08	−R0.03	−R0.20	−R0.20
		Small	25	−R0.04	−R0.02	−R0.07	−R0.03	−R0.07	−R0.10
	Potatoes	Large	150	R3.87	R3.87	R3.87	R3.98	R3.66	R3.66
		Medium	80	R1.85	R1.85	R1.85	R1.90	R1.73	R1.73
		Small	10	R0.15	R0.17	R0.13	R0.16	R0.13	R0.11
	Summer Vegetables	Large	50	R0.86	R0.86	R0.86	R0.90	R0.78	R0.78
		Medium	30	R0.33	R0.33	R0.33	R0.35	R0.28	R0.28
		Small	6	R0.02	R0.04	−R0.00	R0.02	R0.01	−R0.02
	Winter Vegetables	Large	50	R1.46	R1.46	R1.46	R1.50	R1.38	R1.38
		Medium	30	R0.69	R0.69	R0.69	R0.71	R0.64	R0.64
		Small	6	R0.09	R0.11	R0.07	R0.10	R0.08	R0.06
	Wheat	Large	170	−R0.03	−R0.03	−R0.03	R0.07	−R0.24	−R0.24
		Medium	110	−R0.19	−R0.19	−R0.19	−R0.12	−R0.32	−R0.32
		Small	40	−R0.04	−R0.01	−R0.06	−R0.01	−R0.09	−R0.11
Medium term	Lucerne	Large	60	R0.39	R0.39	R0.39	R0.43	R0.31	R0.31
		Medium	30	−R0.04	−R0.04	−R0.04	−R0.02	−R0.08	−R0.08
		Small	20	R0.15	R0.17	R0.12	R0.16	R0.12	R0.10
Long term	Grapes – Fresh	Large	60	R1.62	R1.62	R1.62	R1.70	R1.44	R1.44
		Medium	22	R0.30	R0.30	R0.30	R0.33	R0.23	R0.23
		Small	8	R0.14	R0.16	R0.11	R0.15	R0.11	R0.09
	Grapes – Wine	Large	40	R0.02	R0.02	R0.02	R0.07	−R0.07	−R0.07
		Medium	28	−R0.13	−R0.13	−R0.13	−R0.09	−R0.19	−R0.19
		Small	10	−R0.02	R0.01	−R0.04	−R0.01	−R0.04	−R0.07
	Grapes – Dry	Large	40	R0.08	R0.08	R0.08	R0.12	R0.01	R0.01
		Medium	28	−R0.08	−R0.08	−R0.08	−R0.06	−R0.14	−R0.14
		Small	10	−R0.00	R0.02	−R0.03	R0.01	−R0.02	−R0.05
	Citrus – Oranges	Large	80	R3.36	R3.36	R3.36	R3.45	R3.16	R3.16
		Medium	40	R1.44	R1.44	R1.44	R1.49	R1.34	R1.34
		Small	15	R0.58	R0.60	R0.55	R0.59	R0.54	R0.52
	Palm Dates	Large	250	R48.12	R48.12	R48.12	R48.42	R47.48	R47.48
		Medium	100	R18.96	R18.96	R18.96	R19.09	R18.71	R18.71
		Small	15	R2.77	R2.80	R2.75	R2.79	R2.74	R2.71

6.2 Groot Letaba River System

6.2.1 Water supply curtailment

Scenario Lii 2 (Base Scenario)

The WRPM analysis entails simulating a 1000 probable levels of curtailment for each year of the analysis period, which can be summarised per percentile probability and illustrated in a box-and-whisker plot. For the Groot Letaba River System, Scenario Lii 2 from the *Luvuvhu and Letaba Reconciliation Strategy Study* was adopted for analysis. Output from the WRYM was used to derive the results for the economic indicators. The curtailment of water supply was determined by obtaining the difference between the water requirements of the irrigation schemes and the available supply from the resources. These differences are mainly dictated by the operating rule of Tzaneen Dam.

Therefore, the proportion by which the demand exceeds the supply in the Groot Letaba River System as result from the WRYM analysis was also summarised per percentile probability (Table 120 and Figure 63). The results for Scenario 1 indicated that system curtailments were required in all the years; the most severe curtailments were in 2015.

Figure 62 shows the demand output of Sequence 1 for Channel 39, which supplies Irrigation Block 32 (Magoebaskloof–Vergelegen canal). This demand output file and the supply output file (`plt.out`) are used as input in to the ASM, where a proportion curtailment is derived that feeds into the WIM.

```
CHANNEL DEMANDS as REQUIRED FLOW in (M3/S)

Target Draft = 1   Stochastic Sequence = 1    IRRIGATION BLOCK ABSTRACTION DEMAND (ARC 2) 32 : Irrigationblockno32                  Channel = 39

  YEAR       OCT      NOV      DEC      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP  AVERAGE     TOTAL
 ------------------------------------------------------------------------------------------------------------------------------------
  1920  0.097377 0.261459 0.195406 0.115308 0.025240 0.163995 0.149688 0.193106 0.155000 0.114922 0.213522 0.300876 0.165492     1.986
  1921  0.227329 0.140872 0.175863 0.004368 0.157881 0.262327 0.169405 0.201230 0.214707 0.204025 0.245493 0.287783 0.190940     2.291
  1922  0.285684 0.107361 0.208443 0.018183 0.000000 0.054569 0.231643 0.231971 0.110882 0.204025 0.240081 0.277584 0.164202     1.970
  1923  0.265467 0.091832 0.115903 0.000000 0.000000 0.191694 0.183191 0.097377 0.182134 0.114066 0.186827 0.288969 0.143122     1.717
  1924  0.218263 0.159378 0.022133 0.150259 0.000000 0.000000 0.177031 0.228489 0.057226 0.190809 0.202543 0.230568 0.136392     1.637
  1925  0.156179 0.139169 0.078776 0.000000 0.000000 0.047584 0.094876 0.170880 0.136070 0.177063 0.248329 0.288939 0.128155     1.538
  1926  0.264309 0.249155 0.000000 0.000000 0.000000 0.000000 0.139418 0.064248 0.157242 0.203089 0.247450 0.292811 0.134810     1.618
  1927  0.245796 0.172967 0.000000 0.202955 0.000000 0.000000 0.147556 0.217216 0.173942 0.146307 0.199765 0.257770 0.147023     1.764
  1928  0.306392 0.000000 0.000000 0.188985 0.232118 0.180900 0.188699 0.233188 0.214707 0.204025 0.249067 0.144713 0.178566     2.143
  1929  0.269553 0.107075 0.001214 0.048675 0.092228 0.205955 0.049477 0.230147 0.210021 0.197990 0.223819 0.289650 0.160484     1.926
 ------------------------------------------------------------------------------------------------------------------------------------
   AVE  0.019470 0.011911 0.006648 0.006073 0.004229 0.009225 0.012758 0.015565 0.013433 0.014636 0.018807 0.022164 0.154919     0.155
 TOTAL     0.234    0.143    0.080    0.073    0.051    0.111    0.153    0.187    0.161    0.176    0.226    0.266    1.549    18.590
 ====================================================================================================================================
```

Figure 62: Output file (`dem.out`) from Groot Letaba WRYM analysis (Scenario Lii 2)

Table 120 simulates the probability distribution of the various curtailment levels for all 1000 simulated sequences per selected list of percentiles. These probabilities are illustrated graphically in Figure 63 and the levels of curtailment for the 5% probability distribution are indicated on the graph. Of a 1000 sequences, there was a 5% probability in the year 2014 that the level of curtailment would be 0.331 or more. For the year 2020, the results indicated that the level of curtailment could be as much as 0.987. This level of curtailment is applicable to the irrigation sector and based on the defined risk of curtailment/ assurance of supply criteria. The proportion of curtailment for the most severe curtailment of 0.987 in 2020 would entail the following for the irrigation sector:

Table 119: Level and proportion of curtailment for the irrigation sector

User sector	Percentage of water demand to be supplied			
	99.5% assurance 1 in 200 year	99% assurance 1 in 100 year	98% assurance 1 in 50 year	90% assurance 1 in 10 year
Irrigation	X	X	X	100
Level of curtailment	4	3	2	1
Proportion of level curtailed	X	X	X	0.987

Table 120: Annual curtailment levels for the irrigation sector – Groot Letaba (Scenario Lii 2)

Percentile	Level of curtailment									
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
0%	0.437	0.754	0.685	0.827	0.810	0.801	0.987	0.887	0.595	0.547
0.5%	0.432	0.521	0.560	0.588	0.668	0.521	0.507	0.505	0.502	0.512
1%	0.431	0.514	0.522	0.533	0.524	0.500	0.504	0.499	0.500	0.505
5%	0.422	0.486	0.483	0.485	0.477	0.473	0.477	0.474	0.477	0.477
25%	0.367	0.420	0.402	0.377	0.366	0.364	0.377	0.384	0.372	0.363
50%	**0.331**	**0.297**	**0.282**	**0.272**	**0.267**	**0.266**	**0.267**	**0.270**	**0.269**	**0.269**
75%	0.197	0.220	0.215	0.209	0.207	0.203	0.205	0.206	0.205	0.209
95%	0.125	0.146	0.138	0.130	0.134	0.130	0.137	0.138	0.136	0.138
99%	0.107	0.110	0.103	0.092	0.104	0.102	0.103	0.109	0.095	0.104
99.5%	0.096	0.104	0.094	0.087	0.095	0.098	0.093	0.093	0.090	0.094
100%	0.076	0.087	0.089	0.083	0.079	0.084	0.082	0.081	0.084	0.066

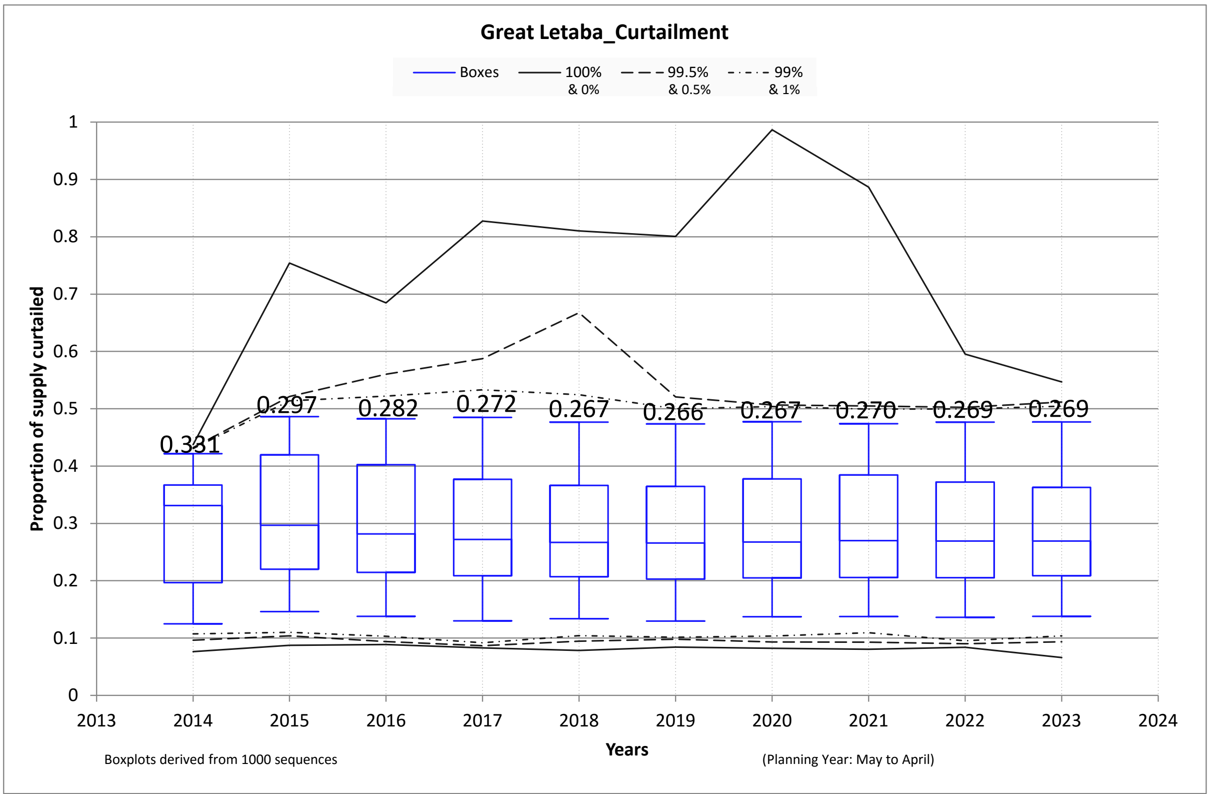


Figure 63: Curtailment plot for irrigation use in the Groot Letaba River System (Scenario Lii 2)

Figure 64 illustrates the storage projection plot for the combined Groot Letaba System over a 10-year period with a starting storage of 50% in May 2014. The box-and-whisker plots indicate the probability distribution of the system storage for each month over the 10-year analysis period. The system has a full storage capacity of 268 million m³, which include Magoebaskloof, Hans Merensky, Dap Naude, Ebenezer, Vergelegen and Tzaneen Dam. Generally, the graph follows a similar pattern to the graph of Tzaneen Dam shown in Figure 66 since Tzaneen Dam is 68% of the total system storage.

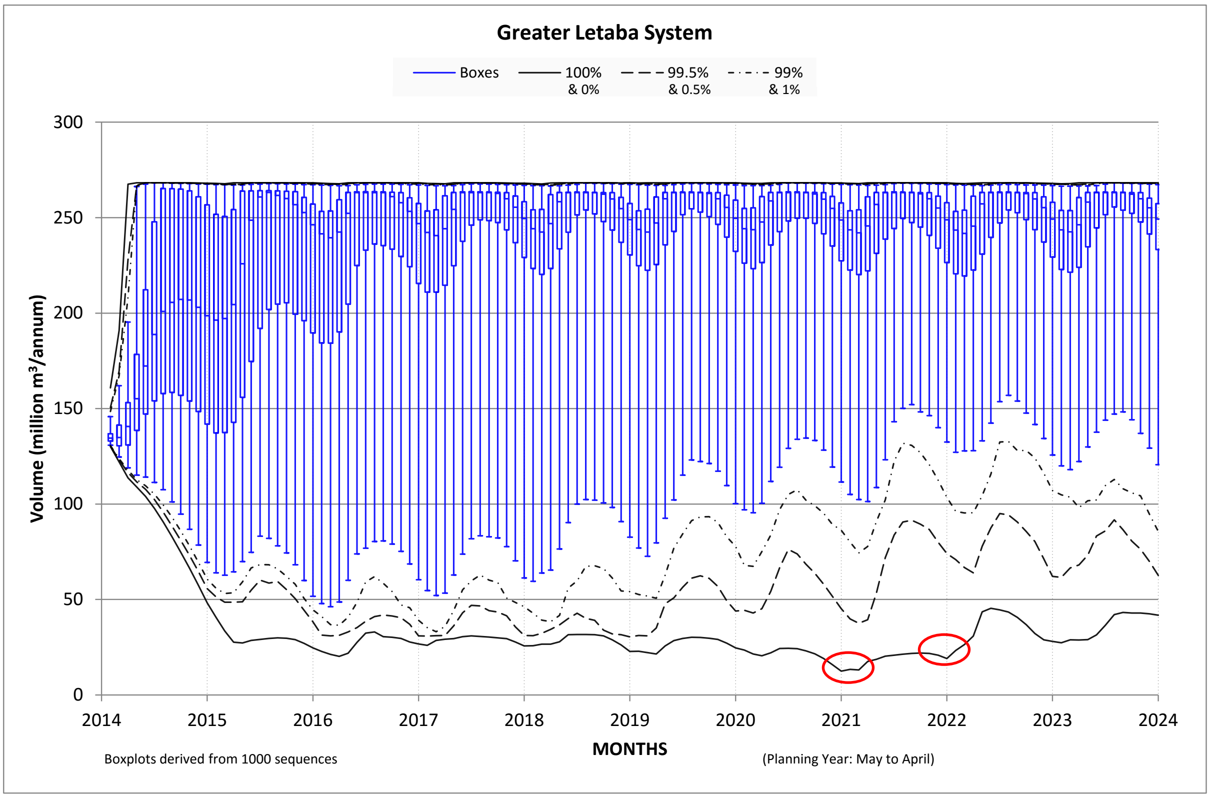
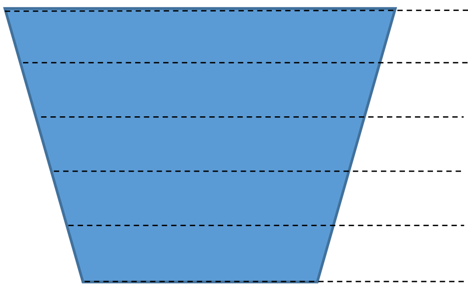


Figure 64: Storage projection plot of the Groot Letaba River System

Figure 64 shows that there is a probability for the system storage to drop significantly in the years 2021 and 2022. These are also the years with the probabilities for the most severe curtailments; however, only with a probability of less than 0.5%. Median projected storage of the Groot Letaba System over the 10-year period is seldom less than 250 million m³, which can mainly be attributed to the dam-operating rules of Tzaneen Dams as shown in Figure 65.

Tzaneen Dam



Storage %	Level m (local)	Restriction %
100	10	
98.3	9.76	0
96.7	9.52	30
95	9.28	40
5	1.38	50
0	0	100

Figure 65: Operating rule of Tzaneen Dam

Figure 66 illustrates the storage projection plot for Tzaneen Dam for the analysis period, which indicates the various storage capacities at which restrictions on the irrigation sector are applicable. The strict rules on the Tzaneen Dam for irrigators, which impose restrictions as soon as the dam levels are below 98.3%, render some form of restrictions constantly applied.

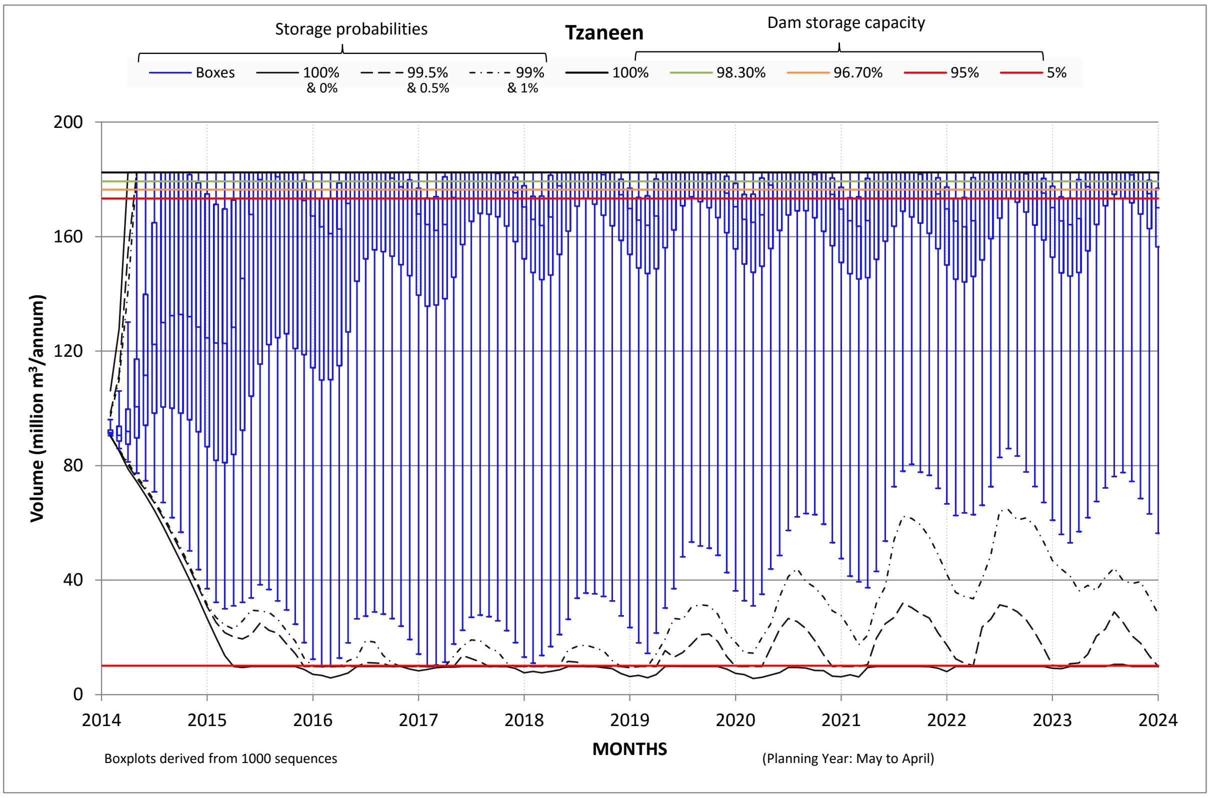


Figure 66: Storage projection plot of Tzaneen Dam

Even in very wet sequences, the chance is good that the dam is not full for a whole year consecutively, in which case there will be supply deficits. In Section 6.2.2, the socio-economic effect of the deficit in supply in the Groot Letaba River System is summarised per economic indicator and illustrated graphically.

6.2.2 Socio-economic impacts

This section summarises and illustrates the present value for each of the socio-economic indicators per scenario graphically as result of the execution of the ASM. A 1000 simulated values were generated for each economic indicator over a period of 10 years and discounted at 0%, 6% and 8% respectively. The main comparison among the results focuses on the present values discounted at 0%.

Figure 67 uses a probability distribution table to summarise the 1000 simulated values for ease of interpretation. A risk-weighted result (average) was obtained for each economic indicator. The summary tables and box-and-whisker plots for each scenario analysed are presented below.

The economic impact of this set of rules and scenario for the Groot Letaba System is summarised in Table 121 per average present value and average annual value for each economic indicator.

Table 121: Groot Letaba System scenario-economic indicator matrix (present value and annual averages)

Scenario	GDP loss (R million m³)		Employment loss numbers		Household income loss (R million m³)	
	Present value	Annual	Present value	Annual	Present value	Annual
Sc Lii 2	5 931	531	87 432	874	3 114	311

Detail results are shown in Figure 67 to Figure 73.

Scenario Lii 2 (Base Scenario) Groot Letaba System

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	14 825	10 832	9 845	119 136	87 403	79 577	7 783	5 687	5 169
1	12 382	9 193	8 387	110 429	81 558	74 380	6 501	4 826	4 403
5	11 145	8 233	7 485	106 020	78 137	71 164	5 851	4 323	3 930
10	10 293	7 596	6 950	102 979	75 867	69 256	5 404	3 988	3 649
15	9 749	7 234	6 609	101 043	74 577	68 039	5 118	3 798	3 470
20	9 412	7 002	6 379	99 841	73 749	67 220	4 942	3 676	3 349
30	8 890	6 578	6 022	97 981	72 240	65 947	4 668	3 454	3 161
40	8 470	6 273	5 729	96 483	71 153	64 902	4 447	3 294	3 008
50	8 074	5 940	5 422	95 071	69 964	63 810	4 239	3 118	2 847
60	7 723	5 704	5 213	93 820	69 124	63 066	4 055	2 995	2 737
70	7 338	5 398	4 936	92 449	68 032	62 076	3 853	2 834	2 591
80	6 936	5 105	4 654	91 015	66 991	61 069	3 641	2 680	2 443
85	6 660	4 912	4 475	90 033	66 299	60 436	3 497	2 579	2 350
90	6 428	4 710	4 273	89 205	65 579	59 714	3 375	2 473	2 243
95	5 947	4 380	3 975	87 487	64 403	58 650	3 122	2 299	2 087
99	5 430	3 950	3 585	85 645	62 870	57 260	2 851	2 074	1 882
99.9	4 880	3 547	3 211	83 687	61 433	55 927	2 562	1 862	1 686
Average:	8 235	6 079	5 548	95 644	70 460	64 257	4 323	3 192	2 913

Figure 67: Present values of economic indicators in the Groot Letaba System

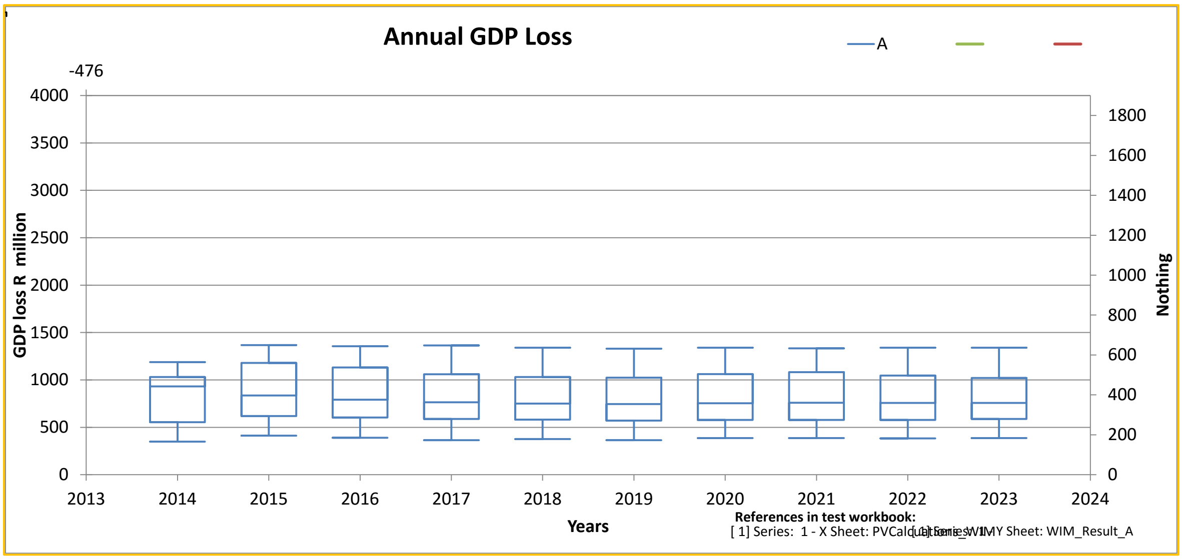


Figure 68: Annual GDP loss over analysis period

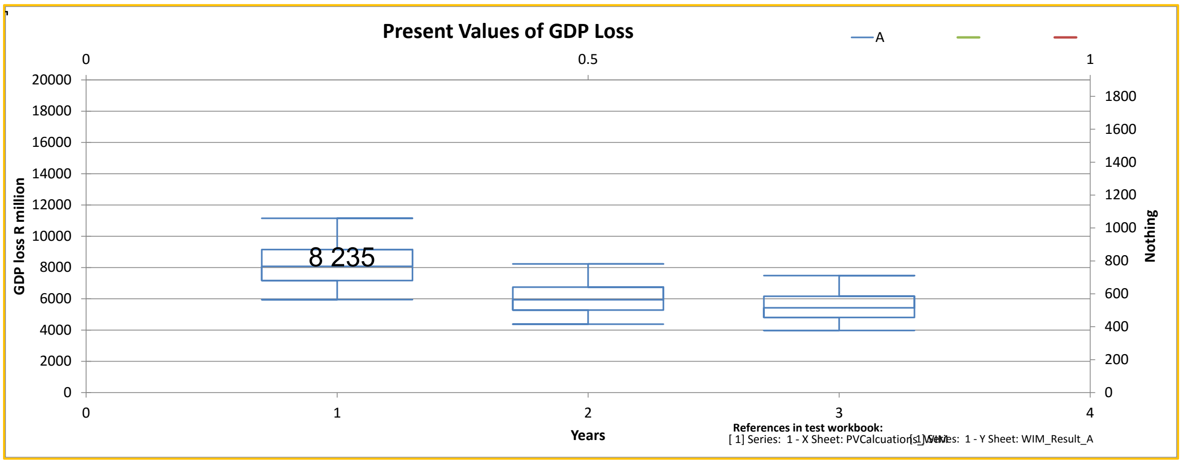


Figure 69: GDP loss per discount rates of 0%, 6% and 8%

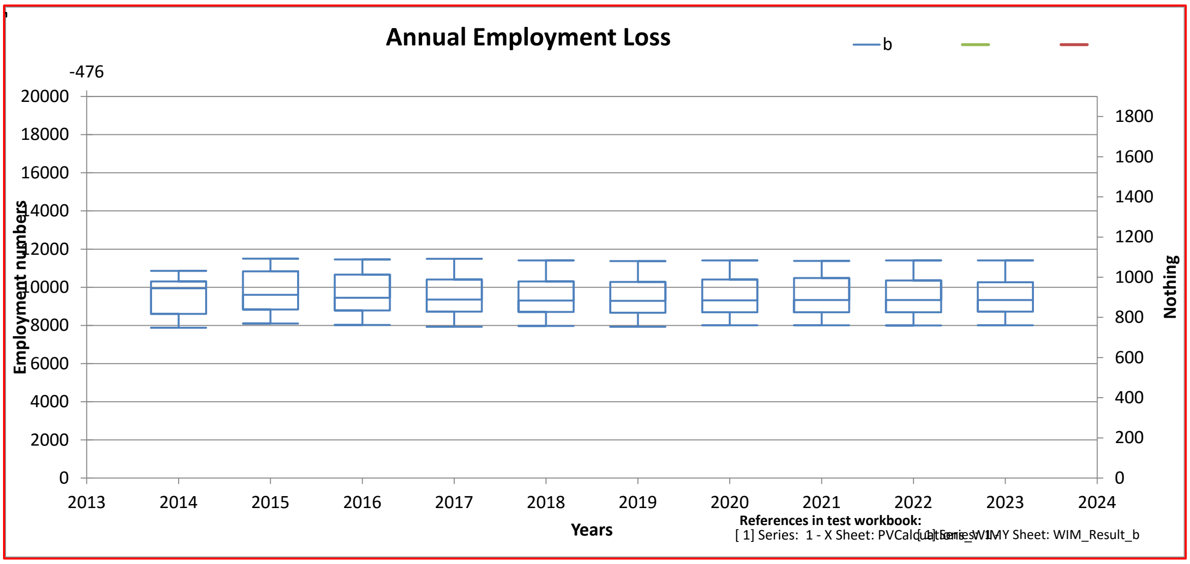


Figure 70: Annual employment loss over analysis period

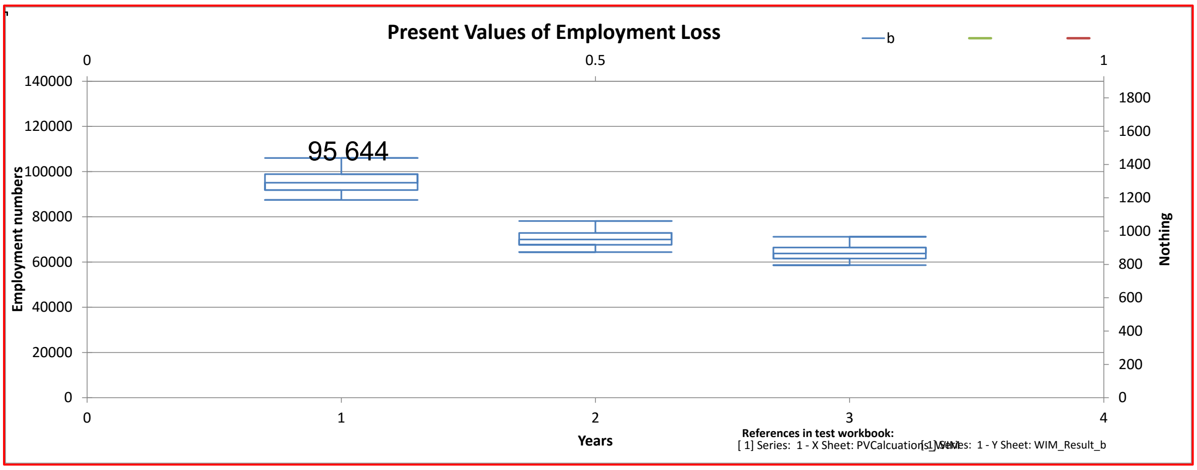


Figure 71: Employment loss per discount rates of 0%, 6% and 8%

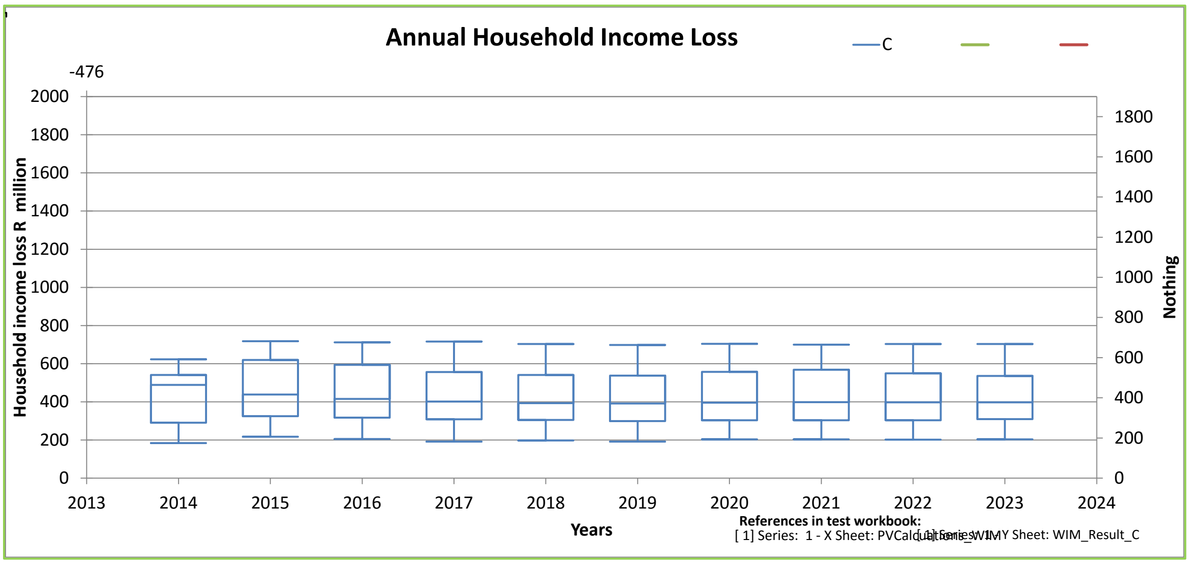


Figure 72: Annual household income loss over analysis period

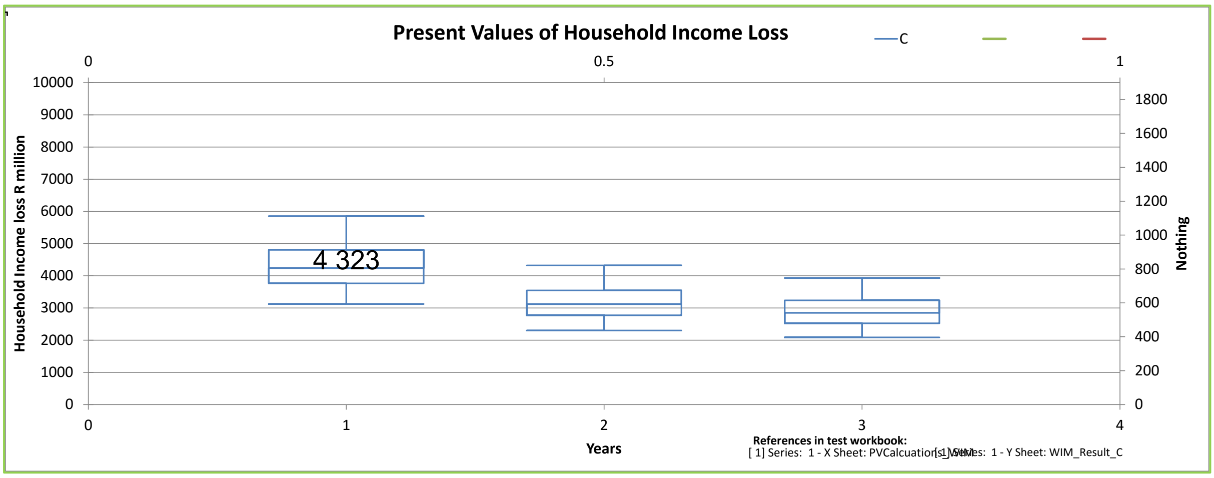


Figure 73: Household income loss per discount rates of 0%, 6% and 8%

6.2.3 Farm producer viability

Table 122 represents the viability results for the Groot Letaba River System at a water supply curtailment of 15%. The main points from the analysis are:

- Only long-term crops are affected when economic scenarios are included.
- Litchis is the prominent crop, which is evident in all the unviable results.
- Medium-scale farmers were unviable in Option 5 and Option 6, but small-scale farmers remained viable due to a standardised reduced managerial fee for small-scale farmers.

Table 123, Table 124 and Table 125 indicate the feasibility for crop production in the Groot Letaba River System at 15%, 30% and 50% water supply curtailments respectively for different farm unit sizes. The farm nett income reduces as the water supply curtailment to the system increases; however, the larger farms and medium-term crops tend to be affected least.

Table 122: Viability results for the Groot Letaba River System

<table>
<tr><td colspan="2">Water Supply: 15% Curtailment</td><td colspan="3">(30% | 3.3%)</td><td colspan="6">Small-scale Management Compensation Curtailed (30%,25%,35%|3.3%)</td><td colspan="6">Real Yield Curtailment (2.5%, 5.0%| 30%)</td><td colspan="3">(35% | 5%)</td></tr>
<tr><td colspan="2">Description</td><td colspan="3">Option 1: Most Likely</td><td colspan="3">Option 2</td><td colspan="3">Option 3</td><td colspan="3">Option 4</td><td colspan="3">Option 5</td><td colspan="3">Option 6: Extreme</td></tr>
<tr><td colspan="2">A) Management Compensation Deduct (%)</td><td colspan="2">0%</td><td>30%</td><td colspan="2">0%</td><td>25%</td><td colspan="2">0%</td><td>35%</td><td colspan="2">0%</td><td>30%</td><td colspan="2">0%</td><td>30%</td><td colspan="2">0%</td><td>35%</td></tr>
<tr><td colspan="2">B) Return on Capital: Real Yield Rate (%)</td><td colspan="9">3.32%</td><td colspan="3">2.50%</td><td colspan="6">5.0%</td></tr>
<tr><td colspan="2">Economical Scale</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td></tr>
<tr><td colspan="2">Number of Unviable Crops</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>1</td><td>-</td><td>-</td><td>1</td><td>-</td></tr>
<tr><td colspan="2">Unviable Crop Name</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Litchi</td><td></td><td></td><td>Litchi</td><td></td></tr>
<tr><td rowspan="5">Short Term</td><td>Maize</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Industrial Tomatoes</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Fresh Tomatoes</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Summer Vegetables</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Winter Vegetables</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Medium Term</td><td>Bananas</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="6">Long Term</td><td>Macadamias</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Citrus – Oranges</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Citrus – Grapefruit</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Avocados</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Litchis</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>X</td><td>-</td><td>-</td><td>X</td><td>-</td></tr>
<tr><td>Mangoes</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

Table 123: Feasibility of crop production in Groot Letaba at 15% curtailment

Note: If Nett Income Negative, Not Feasible to Continue Production				Curtailment 15%; Nett Income (R million)					
				Option 1: Most likely	Option 2	Option 3	Option 4	Option 5	Option 6: Extreme
	Crop	Farm Unit Size	Farm Size (Ha)	30% Fee, 3.3% Real Yield	25% Fee, 3.3% Real Yield	35% Fee, 3.3% Real Yield	30% Fee, 2.5% Real Yield	30% Fee, 5% Real Yield	35% Fee, 5% Real Yield
Short Term	Fresh Tomatoes	Large	250	R4.55	R4.55	R4.55	R4.58	R4.50	R4.50
		Medium	150	R2.04	R2.04	R2.04	R2.06	R2.01	R2.01
		Small	35	R0.16	R0.18	R0.14	R0.16	R0.16	R0.13
	Summer Vegetables	Large	150	R1.22	R1.22	R1.22	R1.26	R1.13	R1.13
		Medium	100	R0.54	R0.54	R0.54	R0.57	R0.49	R0.49
		Small	25	R0.06	R0.09	R0.04	R0.07	R0.05	R0.03
	Winter Vegetables	Large	150	R1.96	R1.96	R1.96	R2.00	R1.88	R1.88
		Medium	100	R0.99	R0.99	R0.99	R1.01	R0.94	R0.94
		Small	25	R0.15	R0.17	R0.13	R0.16	R0.14	R0.12
Medium Term	Bananas	Large	150	R4.85	R4.85	R4.85	R4.94	R4.68	R4.68
		Medium	80	R2.19	R2.19	R2.19	R2.23	R2.11	R2.11
		Small	10	R0.06	R0.08	R0.04	R0.06	R0.05	R0.03
Long Term	Macadamias	Large	50	R2.65	R2.65	R2.65	R2.68	R2.60	R2.60
		Medium	30	R1.03	R1.03	R1.03	R1.04	R1.00	R1.00
		Small	6	R0.61	R0.63	R0.59	R0.61	R0.60	R0.57
	Citrus – Oranges	Large	50	R4.55	R4.55	R4.55	R4.64	R4.35	R4.35
		Medium	30	R2.04	R2.04	R2.04	R2.09	R1.94	R1.94
		Small	6	R0.80	R0.82	R0.78	R0.82	R0.76	R0.74
	Citrus – Grapefruit	Large	170	R2.74	R2.74	R2.74	R2.84	R2.55	R2.55
		Medium	110	R1.14	R1.14	R1.14	R1.18	R1.04	R1.04
		Small	40	R0.46	R0.49	R0.44	R0.48	R0.42	R0.40
	Avocados	Large	60	R0.87	R0.87	R0.87	R0.97	R0.68	R0.68
		Medium	30	R0.20	R0.20	R0.20	R0.25	R0.11	R0.11
		Small	20	R0.11	R0.13	R0.09	R0.13	R0.08	R0.05
	Litchis	Large	60	R0.29	R0.29	R0.29	R0.34	R0.21	R0.21
		Medium	22	R0.01	R0.01	R0.01	R0.03	−R0.05	−R0.05
		Small	8	R0.09	R0.11	R0.06	R0.10	R0.06	R0.04
	Deciduous Fruit	Large	40	R2.58	R2.58	R2.58	R2.68	R2.39	R2.39
		Medium	28	R1.06	R1.06	R1.06	R1.10	R0.96	R0.96
		Small	10	R0.32	R0.34	R0.29	R0.33	R0.29	R0.26
	Mangoes	Large	40	R0.86	R0.86	R0.86	R0.95	R0.66	R0.66
		Medium	28	R0.19	R0.19	R0.19	R0.24	R0.10	R0.10
		Small	10	R0.11	R0.13	R0.08	R0.13	R0.07	R0.05

Table 124: Feasibility of crop production in Groot Letaba at 30% curtailment

Note: If Nett Income Negative, Not Feasible to Continue Production				Curtailment 30%; Nett Income (R million)					
				Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
	Crop	Farm Unit Size	Farm Size (Ha)	30% Fee, 3.3% Real Yield	25% Fee, 3.3% Real Yield	35% Fee, 3.3% Real Yield	30% Fee, 2.5% Real Yield	30% Fee, 5% Real Yield	35% Fee, 5% Real Yield
Short Term	Fresh Tomatoes	Large	250	R3.47	R3.47	R3.47	R3.50	R3.42	R3.42
		Medium	150	R1.50	R1.50	R1.50	R1.52	R1.47	R1.47
		Small	35	R0.10	R0.12	R0.07	R0.10	R0.09	R0.07
	Summer Vegetables	Large	150	R0.86	R0.86	R0.86	R0.90	R0.78	R0.78
		Medium	100	R0.33	R0.33	R0.33	R0.35	R0.28	R0.28
		Small	25	R0.02	R0.04	−R0.00	R0.02	R0.01	−R0.02
	Winter Vegetables	Large	150	R1.46	R1.46	R1.46	R1.50	R1.38	R1.38
		Medium	100	R0.69	R0.69	R0.69	R0.71	R0.64	R0.64
		Small	25	R0.09	R0.11	R0.07	R0.10	R0.08	R0.06
Medium Term	Bananas	Large	150	R3.72	R3.72	R3.72	R3.81	R3.55	R3.55
		Medium	80	R1.63	R1.63	R1.63	R1.67	R1.54	R1.54
		Small	10	R0.02	R0.04	−R0.01	R0.02	R0.01	−R0.01
Long Term	Macadamias	Large	50	R1.99	R1.99	R1.99	R2.01	R1.94	R1.94
		Medium	30	R0.71	R0.71	R0.71	R0.72	R0.69	R0.69
		Small	6	R0.45	R0.47	R0.43	R0.45	R0.44	R0.41
	Citrus – Oranges	Large	50	R3.36	R3.36	R3.36	R3.45	R3.16	R3.16
		Medium	30	R1.44	R1.44	R1.44	R1.49	R1.34	R1.34
		Small	6	R0.58	R0.60	R0.55	R0.59	R0.54	R0.52
	Citrus – Grapefruit	Large	170	R1.92	R1.92	R1.92	R2.02	R1.72	R1.72
		Medium	110	R0.72	R0.72	R0.72	R0.77	R0.63	R0.63
		Small	40	R0.31	R0.33	R0.28	R0.33	R0.27	R0.25
	Avocados	Large	60	R0.43	R0.43	R0.43	R0.52	R0.24	R0.24
		Medium	30	−R0.02	−R0.02	−R0.02	R0.03	−R0.12	−R0.12
		Small	20	R0.03	R0.05	R0.00	R0.05	−R0.01	−R0.03
	Litchis	Large	60	R0.05	R0.05	R0.05	R0.10	−R0.04	−R0.04
		Medium	22	−R0.14	−R0.14	−R0.14	−R0.12	−R0.20	−R0.20
		Small	8	R0.02	R0.04	−R0.01	R0.03	−R0.01	−R0.03
	Deciduous Fruit	Large	40	R1.85	R1.85	R1.85	R1.94	R1.65	R1.65
		Medium	28	R0.69	R0.69	R0.69	R0.74	R0.59	R0.59
		Small	10	R0.21	R0.23	R0.18	R0.22	R0.18	R0.15
	Mangoes	Large	40	R0.43	R0.43	R0.43	R0.52	R0.23	R0.23
		Medium	28	−R0.02	−R0.02	−R0.02	R0.02	−R0.12	−R0.12
		Small	10	R0.03	R0.05	R0.00	R0.04	−R0.01	−R0.03

Table 125: Feasibility of crop production in Groot Letaba at 50% curtailment

Note: If Nett Income Negative, Not Feasible to Continue Production				Curtailment 50%; Nett Income (R million)					
				Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
	Crop	Farm Unit Size	Farm Size (Ha)	30% Fee, 3.3% Real Yield	25% Fee, 3.3% Real Yield	35% Fee, 3.3% Real Yield	30% Fee, 2.5% Real Yield	30% Fee, 5% Real Yield	35% Fee, 5% Real Yield
Short Term	Fresh Tomatoes	Large	250	R2.04	R2.04	R2.04	R2.06	R1.98	R1.98
		Medium	150	R0.78	R0.78	R0.78	R0.80	R0.75	R0.75
		Small	35	R0.01	R0.03	−R0.01	R0.01	R0.01	−R0.02
	Summer Vegetables	Large	150	R0.38	R0.38	R0.38	R0.42	R0.30	R0.30
		Medium	100	R0.04	R0.04	R0.04	R0.07	−R0.01	−R0.01
		Small	25	−R0.04	−R0.02	−R0.06	−R0.03	−R0.05	−R0.07
	Winter Vegetables	Large	150	R0.80	R0.80	R0.80	R0.84	R0.71	R0.71
		Medium	100	R0.29	R0.29	R0.29	R0.32	R0.24	R0.24
		Small	25	R0.01	R0.03	−R0.01	R0.02	R0.00	−R0.02
Medium Term	Bananas	Large	150	R2.21	R2.21	R2.21	R2.29	R2.04	R2.04
		Medium	80	R0.87	R0.87	R0.87	R0.91	R0.78	R0.78
		Small	10	−R0.04	−R0.02	−R0.06	−R0.04	−R0.05	−R0.07
Long Term	Macadamias	Large	50	R1.10	R1.10	R1.10	R1.13	R1.05	R1.05
		Medium	30	R0.28	R0.28	R0.28	R0.30	R0.26	R0.26
		Small	6	R0.24	R0.26	R0.21	R0.24	R0.22	R0.20
	Citrus – Oranges	Large	50	R1.77	R1.77	R1.77	R1.86	R1.57	R1.57
		Medium	30	R0.65	R0.65	R0.65	R0.70	R0.55	R0.55
		Small	6	R0.28	R0.30	R0.26	R0.30	R0.24	R0.22
	Citrus – Grapefruit	Large	170	R0.82	R0.82	R0.82	R0.92	R0.62	R0.62
		Medium	110	R0.18	R0.18	R0.18	R0.22	R0.08	R0.08
		Small	40	R0.10	R0.12	R0.08	R0.12	R0.06	R0.04
	Avocados	Large	60	−R0.16	−R0.16	−R0.16	−R0.07	−R0.35	−R0.35
		Medium	30	−R0.32	−R0.32	−R0.32	−R0.27	−R0.41	−R0.41
		Small	20	−R0.08	−R0.06	−R0.11	−R0.07	−R0.12	−R0.14
	Litchis	Large	60	−R0.27	−R0.27	−R0.27	−R0.23	−R0.36	−R0.36
		Medium	22	−R0.34	−R0.34	−R0.34	−R0.32	−R0.40	−R0.40
		Small	8	−R0.08	−R0.06	−R0.10	−R0.07	−R0.11	−R0.13
	Deciduous Fruit	Large	40	R0.86	R0.86	R0.86	R0.96	R0.67	R0.67
		Medium	28	R0.20	R0.20	R0.20	R0.24	R0.10	R0.10
		Small	10	R0.06	R0.08	R0.04	R0.07	R0.03	R0.01
	Mangoes	Large	40	−R0.15	−R0.15	−R0.15	−R0.06	−R0.35	−R0.35
		Medium	28	−R0.31	−R0.31	−R0.31	−R0.26	−R0.41	−R0.41
		Small	10	−R0.08	−R0.06	−R0.11	−R0.06	−R0.12	−R0.14

6.3 Mhlathuze River System

6.3.1 Water supply curtailment

Scenario 1 (Base Scenario)

The WRPM analysis entails simulating a 1000 probable levels of curtailment for each year of the analysis period, which can be summarised per percentile probability and illustrated in a box-and-whisker plot. The results for Scenario 1 indicated that system curtailments were required in all the years of which the most severe occurred in 2015. Figure 74 shows the results of one of a 1000 sequences indicating a level of curtailment of 0.339 in May 2009 for both the Richards Bay and Tugela sub-systems. There was no curtailment on the Mhlathuze sub-system for sequence 1.

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ACRES INTERNATIONAL LIMITED       MULTI-PURPOSE/MULTI-RESERVOIR SIMULATION PROGRAM        YYYYMMDD      hh:mm:ss         PAGE    1

                                  WRPM CONFIGURATION OF MHLATHUZE BASED ON MWAAS WRYM
                                  Combined W11,W12,W13 Basins  - July 2009   ALL IFR SITES
                                  WRPM ANALYSES : 15 Years

 STOCHASTIC SHORT-TERM PLANNING RESULTS                      RESOURCE ALLOCATION LEVELS                      SEQUENCE S   1

          SYSTEM RBM_SUPP MHLAT     THUK           SYS VOL        FSV          DSV      MONTH

   YEAR

   2008    0.3390    0.0000    0.3390    0.3390    393.3611    393.3611    41.2399      MAY
   2009    0.6978    0.0000    0.6978    0.6978    260.1079    393.3611    41.2399      MAY
   2010    0.4843    0.0000    0.4843    0.4843    326.4005    393.3611    41.2399      MAY
   2011    0.4027    0.0000    0.4027    0.4027    361.4451    393.3611    41.2399      MAY
   2012    0.3709    0.0000    0.3709    0.3709    376.5288    393.3611    41.2399      MAY
   2013    0.3390    0.0000    0.3390    0.3390    393.3611    393.3611    41.2399      MAY
   2014    0.3402    0.0000    0.3402    0.3402    392.7321    393.3611    41.2399      MAY
   2015    0.3390    0.0000    0.3390    0.3390    393.3611    393.3611    41.2399      MAY
   2016    0.4837    0.0000    0.4837    0.4837    324.3036    393.3611    41.2399      MAY
   2017    0.6933    0.0000    0.6933    0.6933    263.4944    393.3611    41.2399      MAY
ACRES INTERNATIONAL LIMITED       MULTI-PURPOSE/MULTI-RESERVOIR SIMULATION PROGRAM        YYYYMMDD      hh:mm:ss         PAGE    2
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Figure 74: Output file (`sys.out`) from Mhlathuze WRPM analysis (Base Scenario)

Table 126 summarises the probability distribution of the various curtailment levels for all 1000 simulated sequences per a selected list of percentiles. These probabilities are illustrated graphically in Figure 75 and the levels of curtailment for the 5% probability distribution are indicated on the graph. For Scenario 1 in the year 2008 out of a 1000 sequences, there was a 5% probability that the level of curtailment would be at 0.339 or more. For the year 2015, the results indicated that the level of curtailment could be as much as 1.932. This level of curtailment is applicable to the complete system and based on the defined risk of curtailment /assurance of supply criteria. The proportion of curtailment for the most severe curtailment of 1.932 in 2015 would entail a full curtailment of level one as well as 0.932 of level three for the irrigation sector (Table 127).

Table 126: Annual curtailment levels for Mhlathuze (Scenario 1)

Percentile	Level of curtailment									
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
0%	0.339	0.902	1.647	3.012	2.400	2.441	3.195	2.499	2.743	3.143
0.5%	0.339	0.878	1.377	1.787	1.879	1.887	1.863	1.904	1.791	1.860
1%	0.339	0.848	1.279	1.662	1.744	1.792	1.749	1.725	1.724	1.784
5%	**0.339**	**0.719**	**0.916**	**1.041**	**1.029**	**1.126**	**1.176**	**1.265**	**1.183**	**1.207**
25%	0.339	0.522	0.631	0.648	0.689	0.697	0.776	0.757	0.760	0.754
50%	0.339	0.420	0.452	0.453	0.472	0.472	0.503	0.515	0.510	0.509
75%	0.339	0.358	0.368	0.366	0.368	0.368	0.370	0.382	0.389	0.384
95%	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339
99%	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339
99.5%	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339
100%	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339

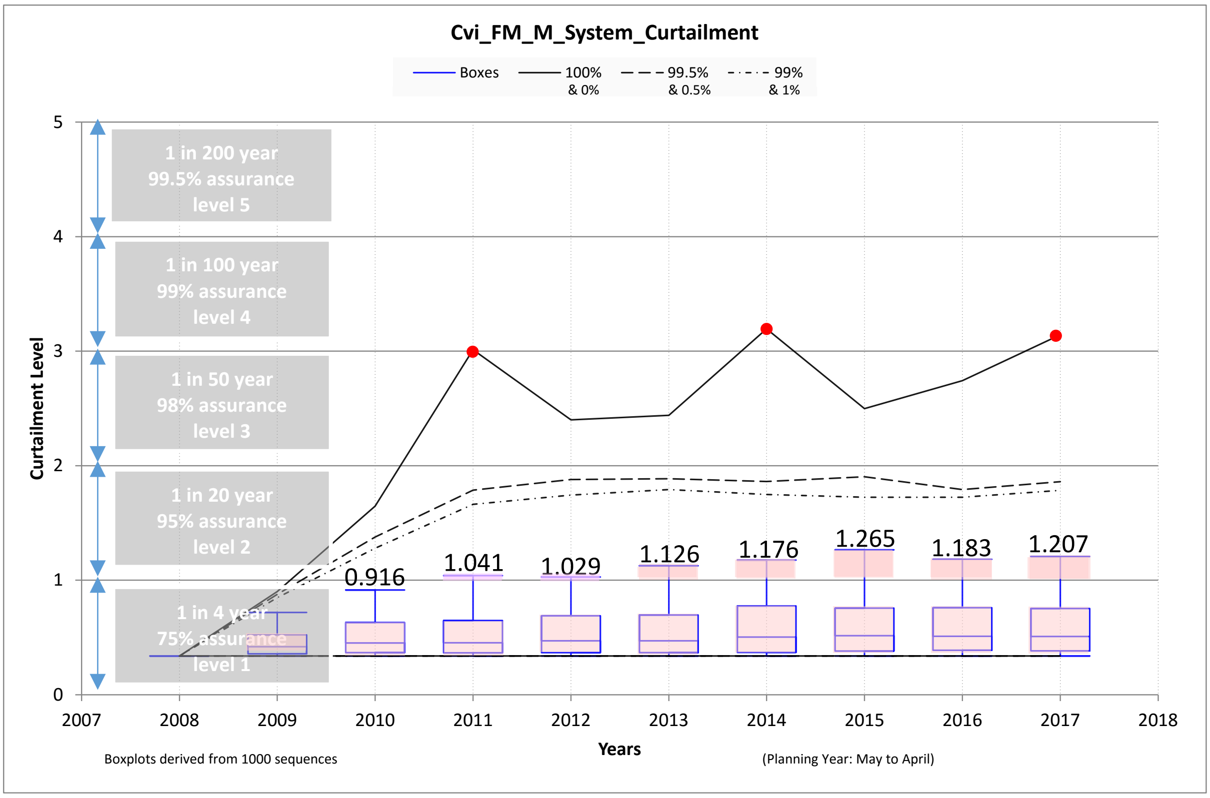


Figure 75: Curtailment plot for Mhlathuze System (Scenario 1)

Table 127: Level and proportion of curtailment for the irrigation sector (Scenarios 1 and 2)

User Sector	% of the water demand to be supplied				
	99.5% assurance 1 in 200 year	99% assurance 1 in 100 year	98% assurance 1 in 50 year	95% assurance 1 in 20 year	75% assurance 1 in 4 year
Irrigation	X	X	50	X	50
Level of curtailment	5	4	3	2	1
Proportion of level curtailed	X	X	0.932	X	1

Figure 76 illustrates the storage projection plot for the Mhlathuze System over a 10-year period with the starting storage at full capacity in May 2008. The box-and-whisker plots indicate the probability distribution of the system storage for each month over the 10-year analysis period. The system has a full storage capacity of 349.7 million m³.

The system curtailment and storage projection plots of all the scenarios analysed are summarised and compared in Table 128 and Table 129 respectively. For all scenarios it can be seen that with the alternative user priority classification or restriction criteria, the system needs to be curtailed as soon as 2010 and more severely than with the original user priority.

The risk criteria was violated for Scenario 1 with both original and alternative user priority options as well as for Scenario 2 with the alternative user priority as indicated with the red colour. For Scenario 3, there was no violation of the risk criteria with either the original or alternative user priority classification. However, with the original user priority classification, results indicate that system curtailments are only required later (2013), but with the probability of being more severe than the alternative user priority classification. In terms of the storage projection plot, there are not major differences between the two user priority options although storage seems to be drawn down less severely for the alternative option because of the earlier system curtailments.

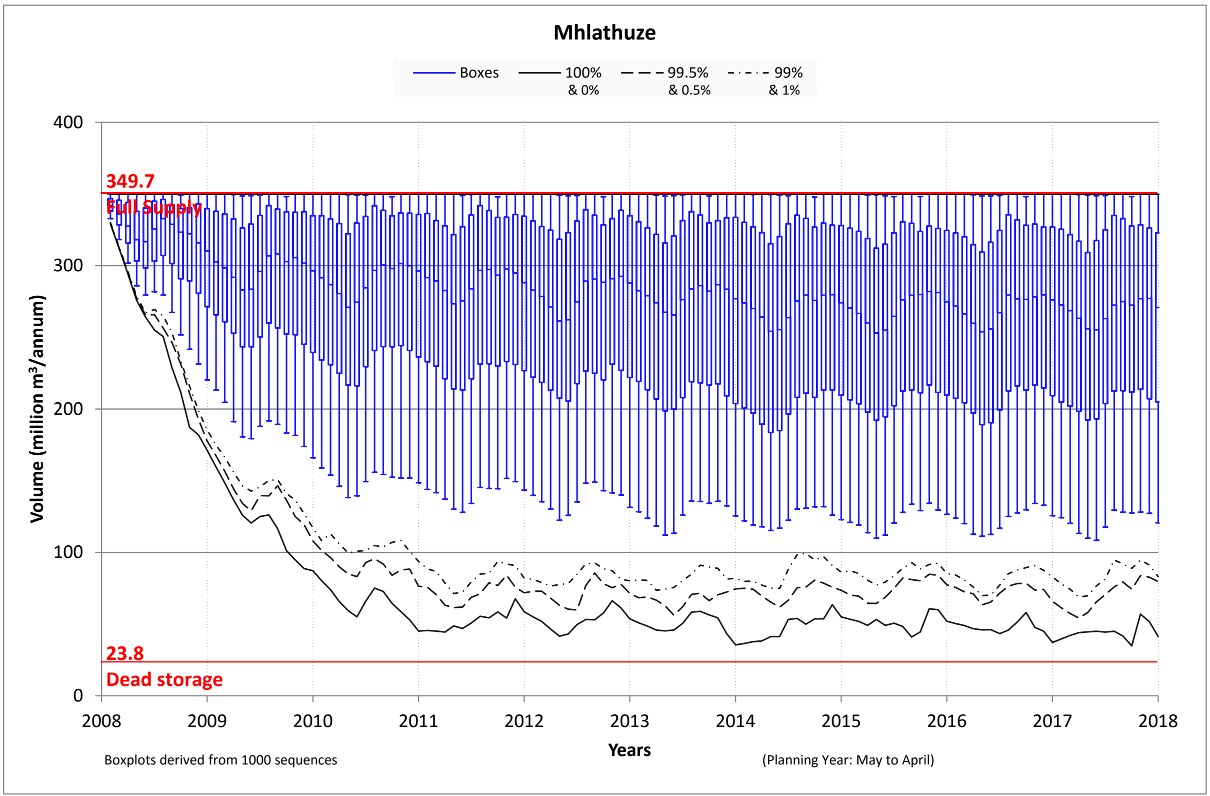
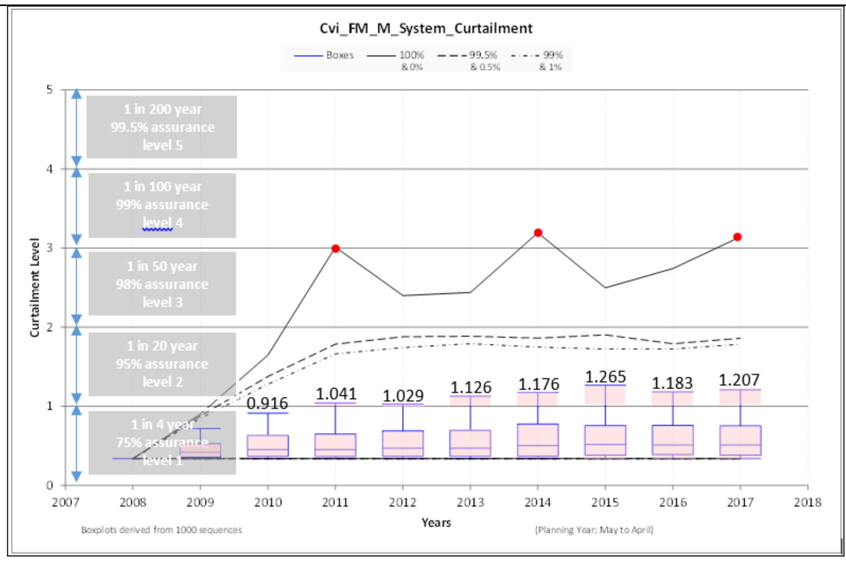
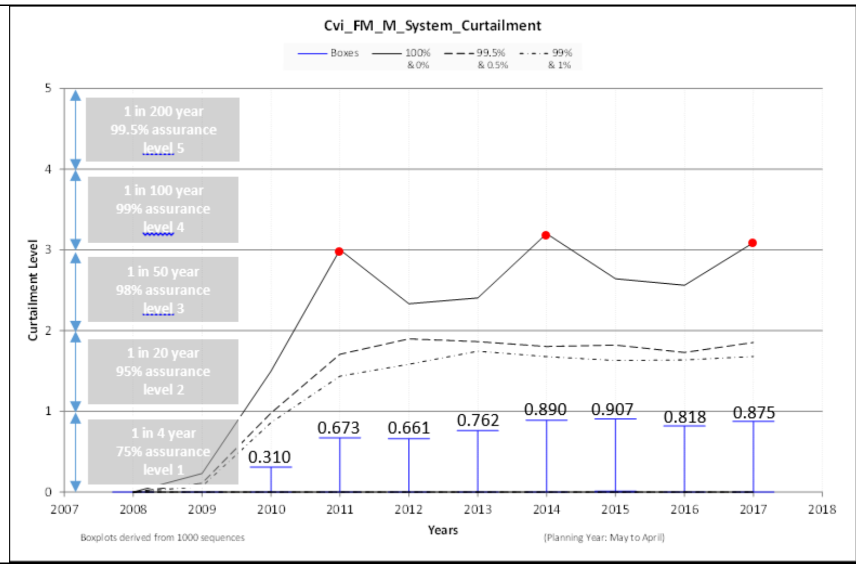
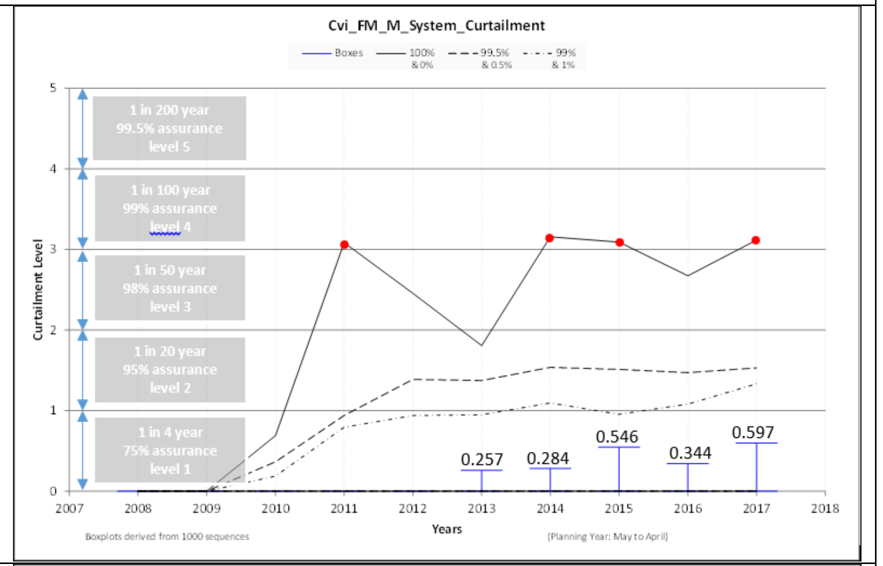


Figure 76: Storage plot for the Mhlathuze System (Scenario 1, 100%–100%)

Table 128: Curtailment of water supply over a 10-year period in the Mhlathuze Water Supply System

<table>
<tr><th>User Priority</th><th>Scenario 1 (100%–100%)</th><th>Scenario 2 (100%–60%)</th><th>Scenario 3 (90%–60%)</th></tr>
<tr><td>Original (call-for-licence study)</td><td>
</td><td>
</td><td>
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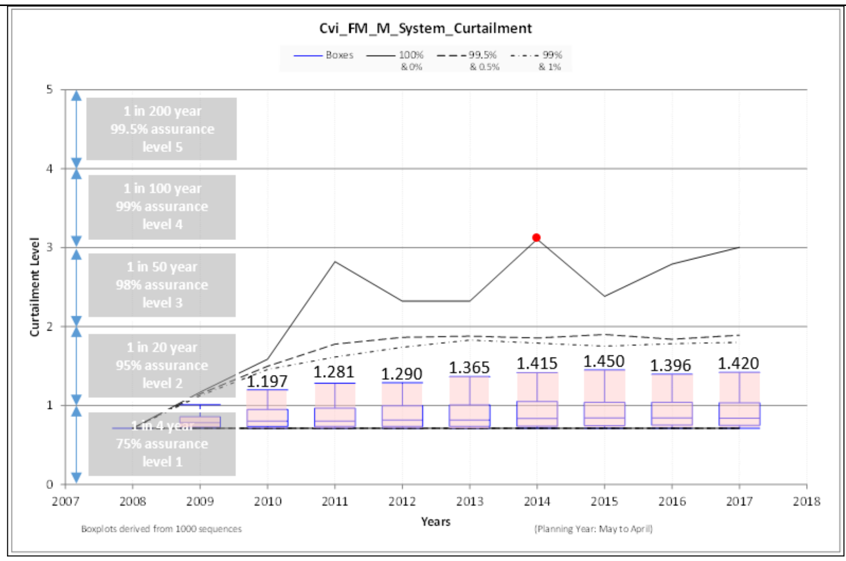
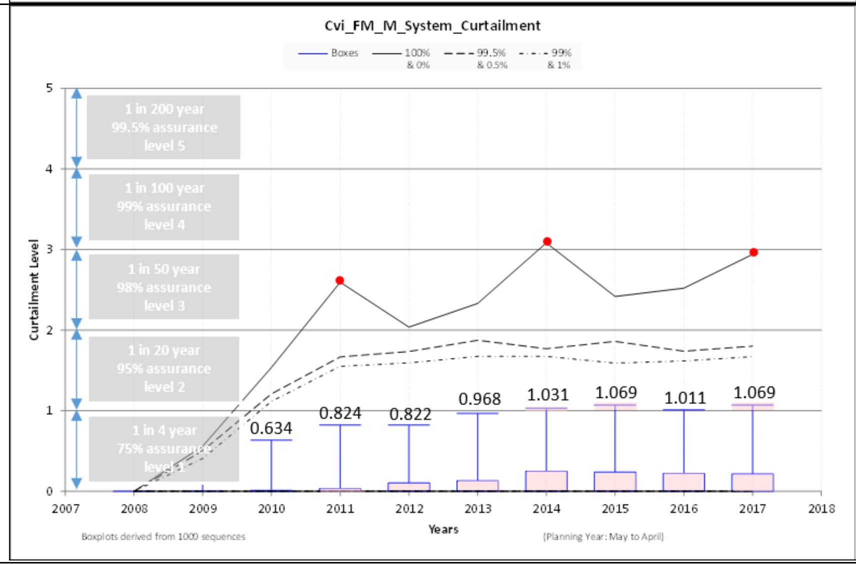
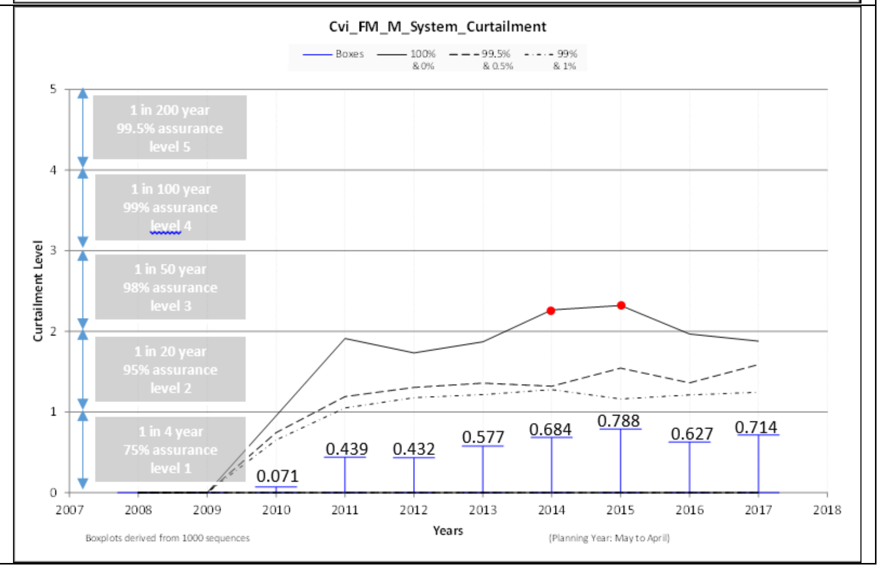
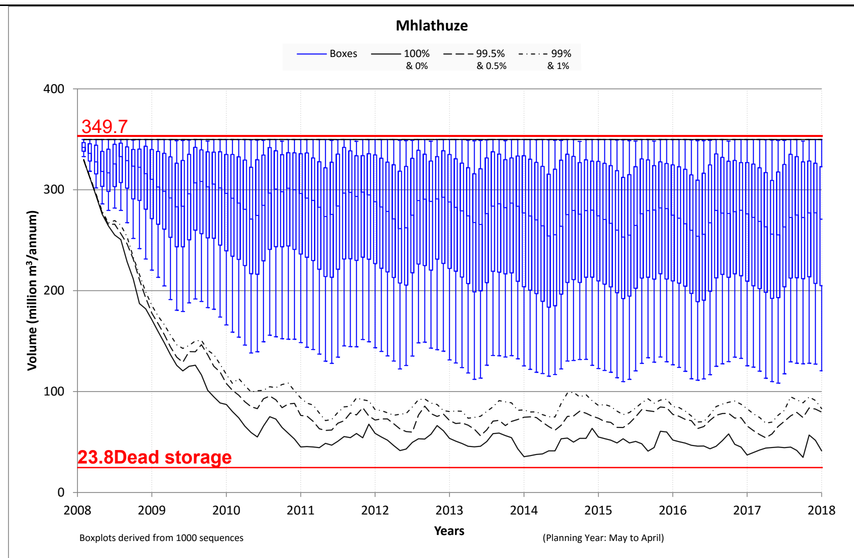
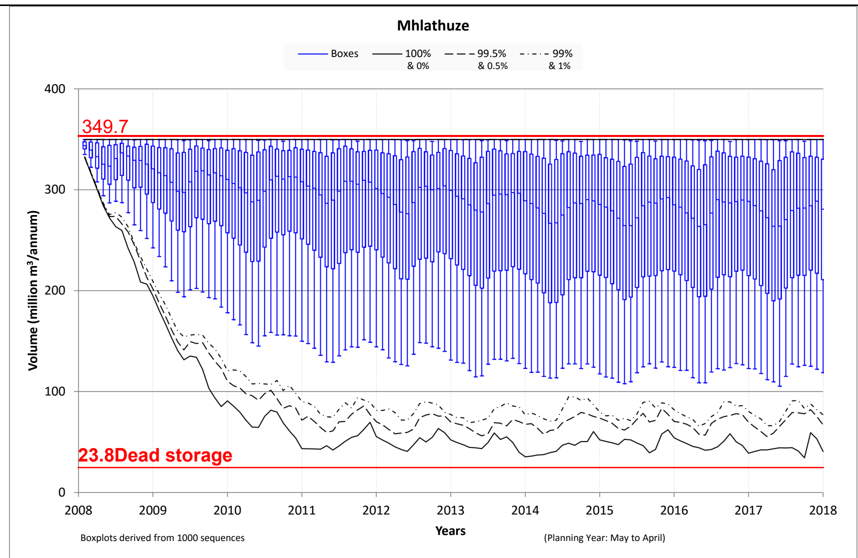
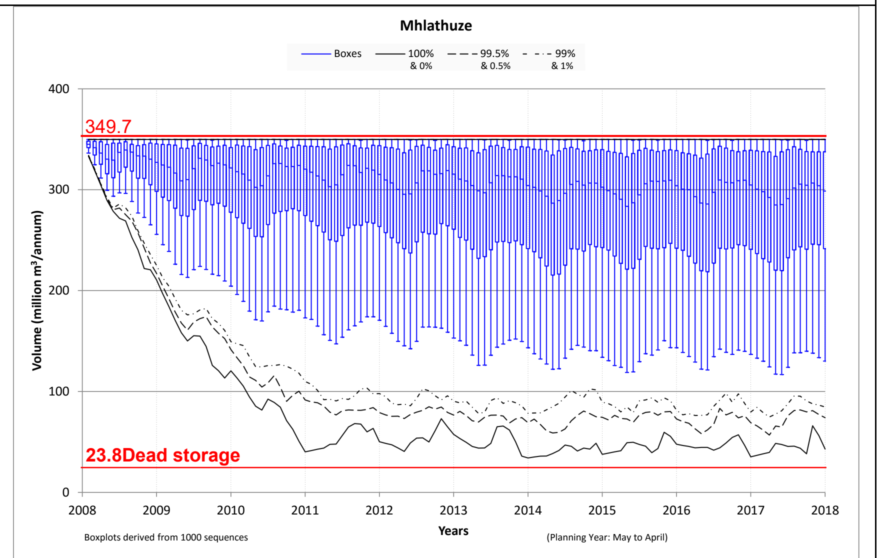
<tr><td>Alternative</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 129: Storage of the Mhlathuze System over a 10-year period

<table>
<tr><th>User Priority</th><th>Scenario 1 (100%–100%)</th><th>Scenario 2 (100%–60%)</th><th>Scenario 3 (90%–60%)</th></tr>
<tr><td>Original (call-for-licence study)</td><td>
</td><td>
</td><td>
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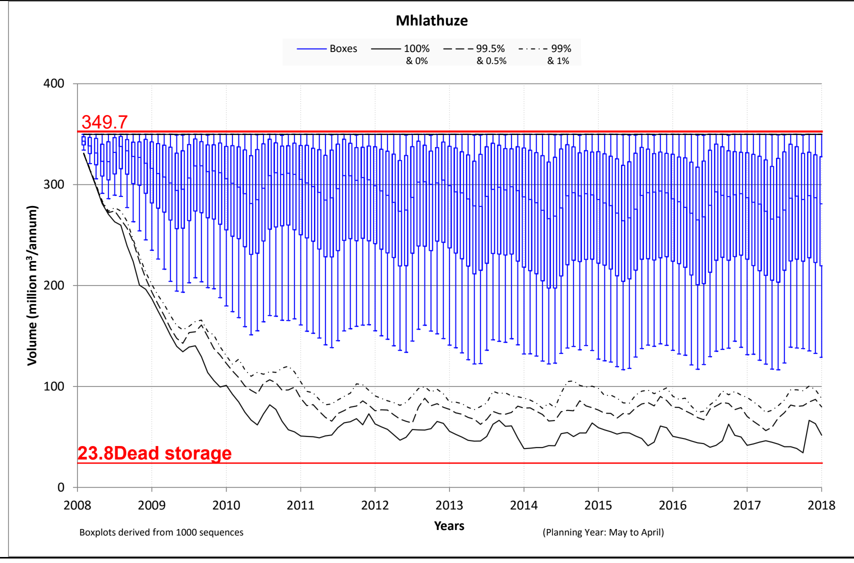
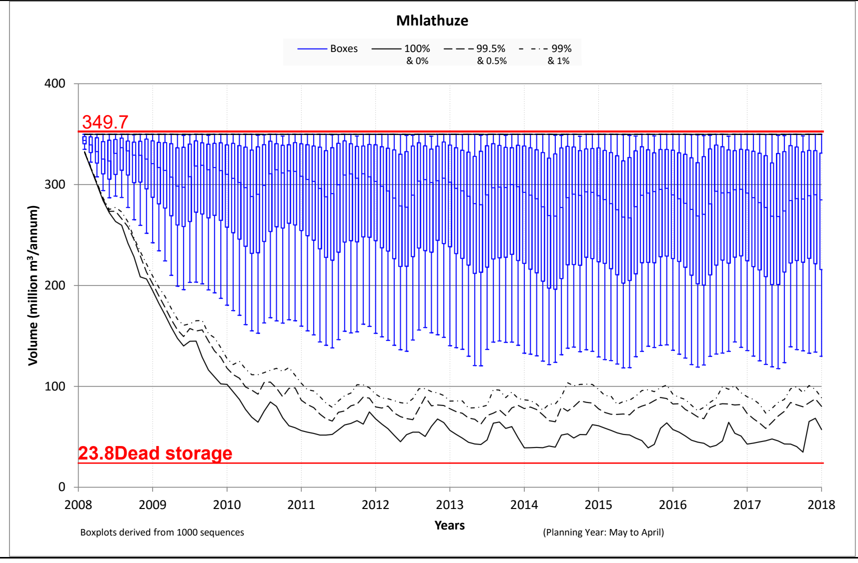
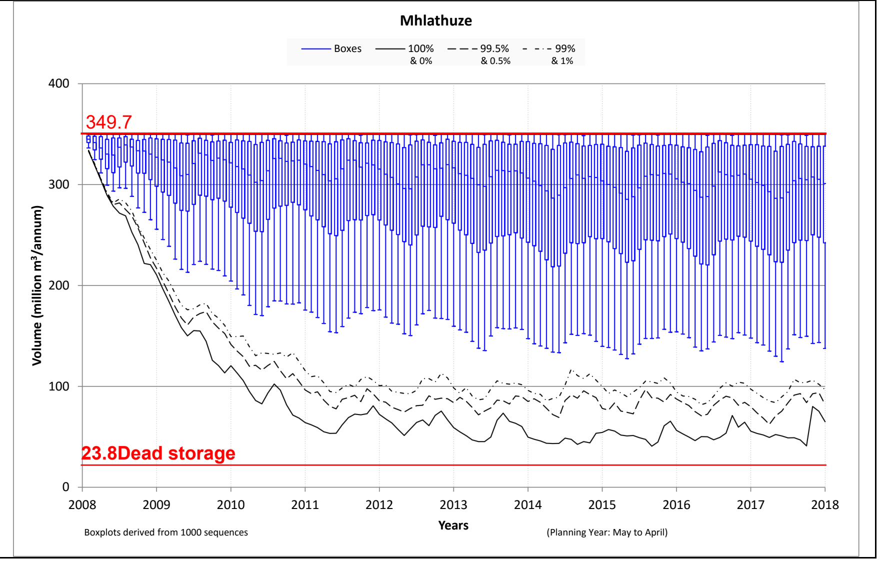
<tr><td>Alternative</td><td>
</td><td>
</td><td>
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6.3.2 Socio-economic impacts

In the following section, the present value for each of the socio-economic indicators per scenario analysed is summarised and illustrated graphically as result of executing the ASM. A 1000 simulated values were generated for each economic indicator over a period of 10 years and discounted at 0%, 6% and 8% respectively. The main comparison between the results focuses on the present values discounted at 0%. A probability distribution table was used (see Figure 77 as example) to summarise the 1000 simulated values for ease of interpretation and a risk-weighted result (average) was obtained for each economic indicator. The summary tables and box-and-whisker plots for each scenario analysed are presented below.

Scenario 1 (Base Scenario): 100%–100% Urban-irrigation demand with original user priority setting

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	5 126	3 683	3 328	26 545	19 231	17 430	2 588	1860	1681
1	4 433	3 161	2 860	24 168	17 439	15 824	2 238	1596	1444
5	3 977	2 854	2 576	22 605	16 387	14 850	2 008	1441	1301
10	3 710	2 671	2 410	21 688	15 759	14 281	1873	1349	1217
15	3 549	2 546	2 301	21 137	15 331	13 906	1792	1286	1162
20	3 438	2 460	2 221	20 757	15 035	13 632	1736	1242	1121
30	3 226	2 334	2 113	20 030	14 603	13 262	1629	1178	1067
40	3 076	2 207	1997	19 515	14 169	12 864	1553	1115	1008
50	2 931	2 116	1916	19 016	13 854	12 588	1480	1068	968
60	2 820	2 039	1845	18 636	13 591	12 344	1424	1030	932
70	2 693	1956	1775	18 201	13 308	12 102	1360	988	896
80	2 548	1853	1687	17 703	12 954	11 802	1287	936	852
85	2 477	1808	1644	17 462	12 799	11 654	1251	913	830
90	2 404	1744	1581	17 211	12 579	11 439	1214	880	799
95	2 295	1682	1532	16 837	12 368	11 270	1159	849	774
99	2 162	1583	1439	16 380	12 029	10 951	1092	800	727
99.9	2 024	1486	1354	15 907	11 696	10 661	1022	750	684
Average:	3 012	2 173	1 968	19 296	14 051	12 764	1521	1097	994

Figure 77: Present values of economic indicators in the Mhlathuze System (Scenario 1)

Scenario 2: 100%–60% Urban-irrigation demand with original user priority setting

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	2 242	1495	1319	12 098	8 172	7 230	1132	755	666
1	1402	971	883	8 129	5 579	5 004	708	490	446
5	1003	672	587	6 100	4 104	3 634	507	339	296
10	790	518	468	4 693	3 240	2 887	399	264	236
15	641	408	355	3 961	2 636	2 324	324	206	179
20	508	338	298	3 422	2 287	2 017	256	171	150
30	338	227	200	2 484	1634	1456	171	115	101
40	232	155	136	1752	1236	1105	117	78	68
50	125	84	74	1307	852	729	63	42	37
60	56	39	34	786	510	451	28	20	17
70	7	5	4	576	341	288	4	2	2
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	272	182	160	1873	1257	1110	138	92	81

Figure 78: Present values of economic indicators in the Mhlathuze System (Scenario 2)

Scenario 3: 90%–60% Urban-irrigation demand with original user priority setting

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	1 779	1 140	992	9 960	6 494	5 674	898	576	501
1	970	652	581	4 992	3 419	3 069	490	329	293
5	611	387	336	3 392	2 305	2 019	308	199	172
10	350	226	196	2 291	1 424	1 234	177	114	99
15	262	165	142	1 576	978	847	132	83	72
20	148	96	85	1 151	774	666	75	48	43
30	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	98	64	56	608	398	348	50	32	28

Figure 79: Present values of economic indicators in the Mhlathuze System (Scenario 3)

Scenario 1a: 100%–100% Urban-Irrigation demand with alternative user priority setting

	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	2 210	1584	1453	16 721	12 032	11 000	1 156	804	734
1	1676	1193	1073	14 712	10 689	9 694	846	602	542
5	1345	954	863	13 577	9 869	8 974	679	482	436
10	1245	891	805	13 234	9 653	8 776	629	450	407
15	1181	844	765	13 015	9 491	8 638	596	426	386
20	1132	814	735	12 845	9 389	8 536	571	411	371
30	1068	775	704	12 626	9 255	8 431	539	391	356
40	1031	750	681	12 501	9 169	8 350	521	378	344
50	992	723	657	12 366	9 078	8 270	501	365	332
60	969	707	642	12 288	9 021	8 217	489	357	324
70	942	689	626	12 194	8 960	8 163	476	348	316
80	916	672	611	12 106	8 901	8 109	463	339	308
85	902	661	602	12 059	8 866	8 080	456	334	304
90	890	651	592	12 017	8 831	8 045	450	329	299
95	874	642	584	11 960	8 798	8 018	441	324	295
99	854	626	570	11 892	8 744	7 969	431	316	288
99.9	831	611	557	11 814	8 695	7 926	420	309	281
Average:	1040	755	685	12 532	9 186	8 364	525	381	346

Figure 80: Present values of economic indicators in the Mhlathuze System (Scenario 1a)

Scenario 2a: 100%–60% Urban-Irrigation demand with original user priority setting

	Discount Rates:								
	0	0.06	0.08						
	Output: GDP			Employment			Household Income		
Percentiles (%):	WIM Metric A (PV) values:			WIM Metric B (PV) values:			WIM Metric C (PV) values:		
0.1	883	603	536	7 989	5 604	5 024	468	312	274
1	578	402	348	5 400	3 803	3 418	292	203	176
5	345	236	208	4 603	3 092	2 758	174	119	105
10	259	175	153	3 737	2 593	2 321	131	89	77
15	215	141	121	3 321	2 291	2 023	109	71	61
20	178	115	102	2 971	2 024	1 812	90	58	52
30	124	84	74	2 526	1 711	1 526	63	42	38
40	92	65	57	2 018	1 396	1 239	47	33	29
50	66	45	40	1 765	1 158	1 025	33	23	20
60	48	33	29	1 296	879	778	24	17	14
70	30	21	18	1 157	719	604	15	11	9
80	14	9	8	601	412	363	7	5	4
85	7	6	5	576	359	303	4	3	3
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	107	72	64	1 874	1 283	1 140	54	36	32

Figure 81: Present values of economic indicators in the Mhlathuze System (Scenario 2a)

Scenario 3a: 90%–60% Urban-irrigation demand with original user priority setting

Percentiles (%):	Output: GDP WIM Metric A (PV) values:			Employment WIM Metric B (PV) values:			Household Income WIM Metric C (PV) values:		
Discount Rates:	0	0.06	0.08						
0.1	627	424	375	6 552	4 438	3 929	317	214	189
1	319	223	195	3 901	2 693	2 381	161	112	99
5	190	126	111	2 631	1 784	1 578	96	64	56
10	128	81	70	2 084	1 357	1 185	64	41	35
15	93	62	54	1 669	1 100	957	47	31	27
20	71	47	41	1 334	887	780	36	24	21
30	37	25	22	719	507	463	19	13	11
40	14	9	8	599	400	343	7	5	4
50	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-
99	-	-	-	-	-	-	-	-	-
99.9	-	-	-	-	-	-	-	-	-
Average:	40	27	23	674	449	396	20	13	12

Figure 82: Present values of economic indicators in the Mhlathuze System (Scenario 3a)

Table 130 summarises the mean present value per economic indicator for each scenario at different discount rates. The scenarios with the alternative user priority option result in lower losses in the economic indicators. However, the curtailment plots indicated a higher probability for restrictions with the alternative user priority classification. With the original user priority, restrictions are only required later and at a lower probability in the lower curtailment levels and at a higher risk of being curtailed more severely in the higher curtailment levels; however, still unlikely.

Table 130: Mean present value per economic indicator and scenario for the Mhlathuze System

Scenario	GDP loss (R million)			Employment loss (numbers)			Household income Loss (R million)		
	0%	6%	8%	0%	6%	8%	0%	6%	8%
Scenario 1	3 012	2 173	1 968	19 296	14 051	12 764	1 521	1 097	994
Scenario 2	272	182	160	1 873	1 257	1 110	138	92	81
Scenario 3	98	64	56	608	398	348	50	32	28
Scenario 1a	1 040	755	685	12 532	9 186	8 364	525	381	346
Scenario 2a	107	72	64	1 874	1 283	1 140	54	36	32
Scenario 3a	40	27	23	674	449	396	20	13	12

Table 131: Present Val of GDP Loss at 0%, 6% and 8

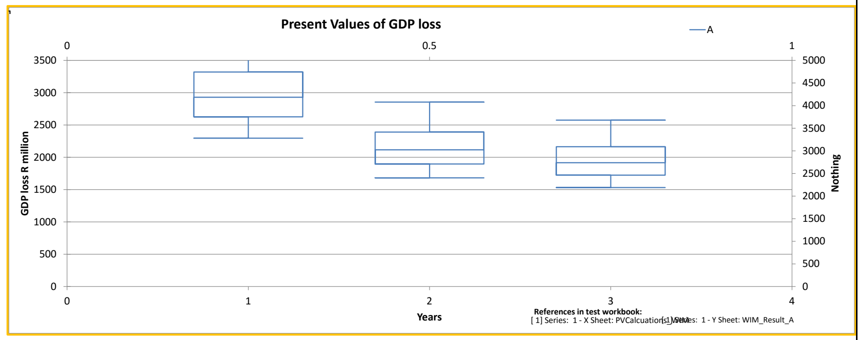
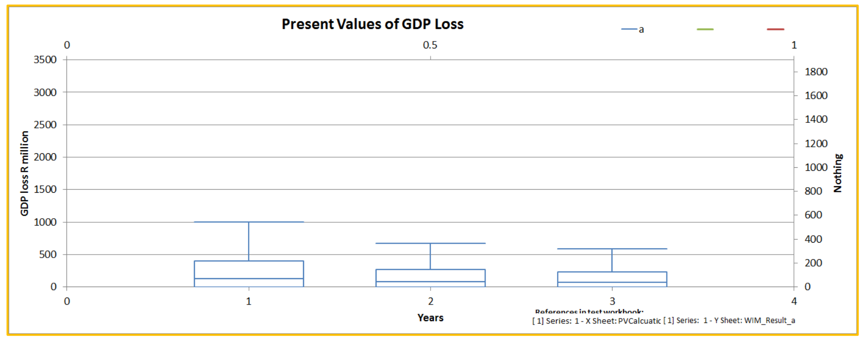
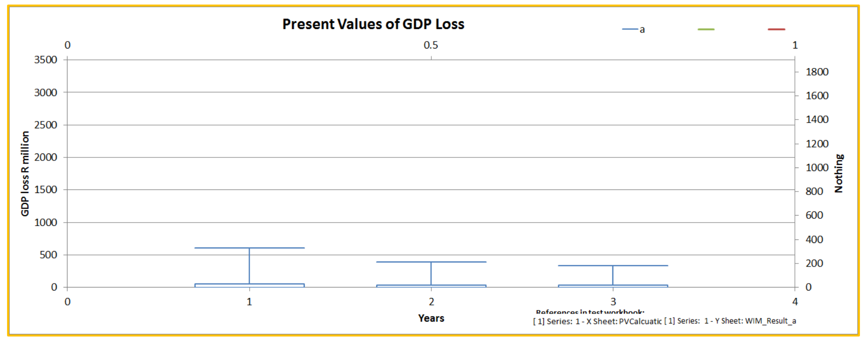
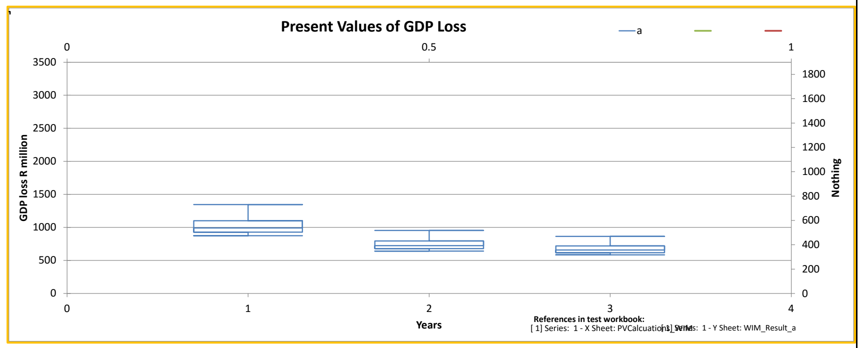
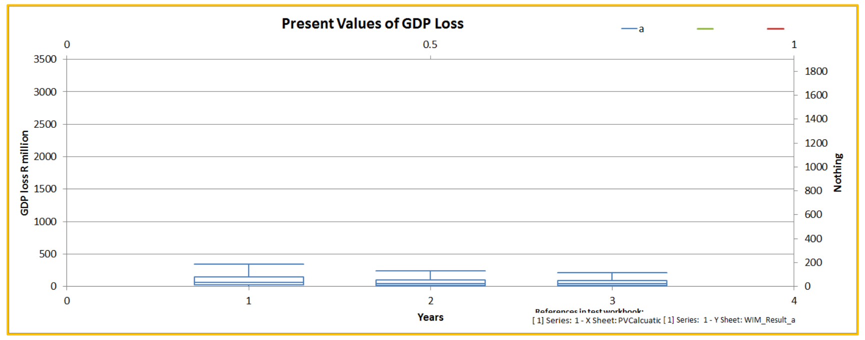
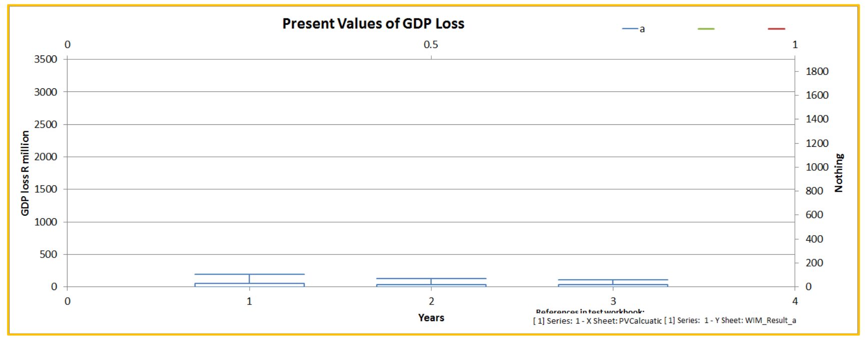
User Priority	Scenario 1 (100%–100%)	Scenario 2 (100%–60%)	Scenario 3 (90%–60%)
Original (call-for-licence study)			
Alternative			

Table 132: Present values of employment loss at 0%, 6% and 8%

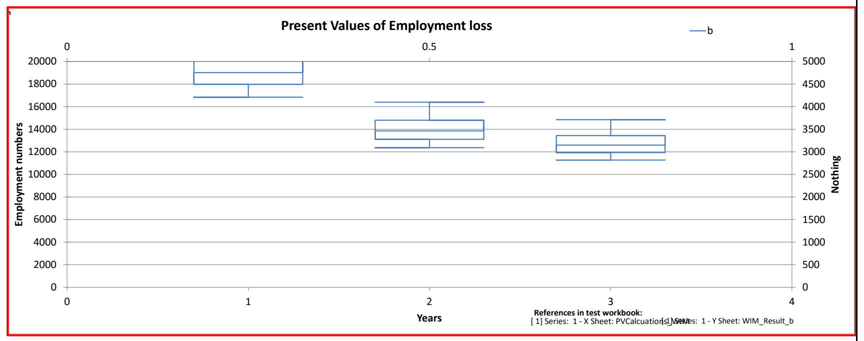
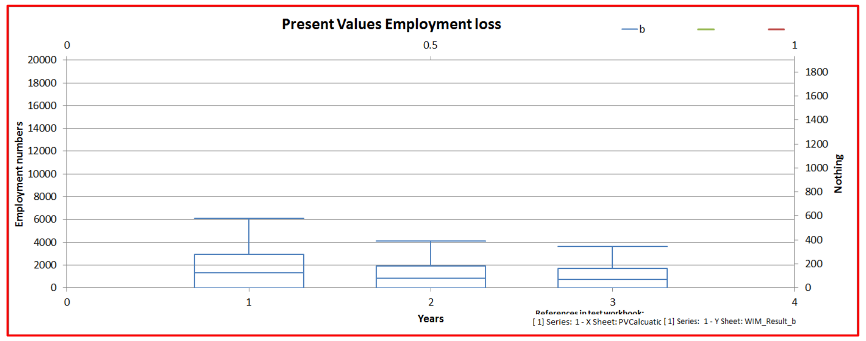
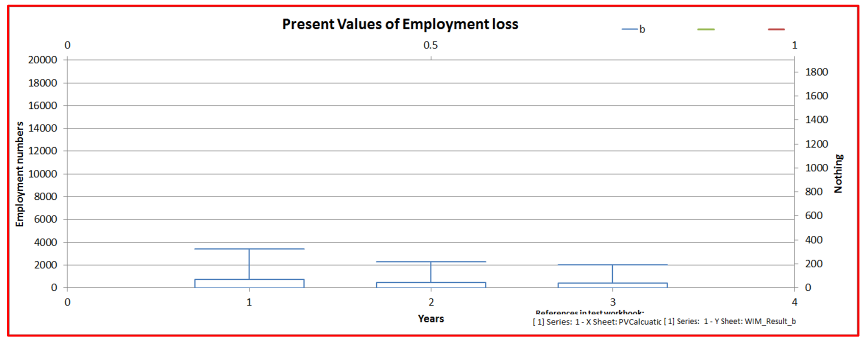
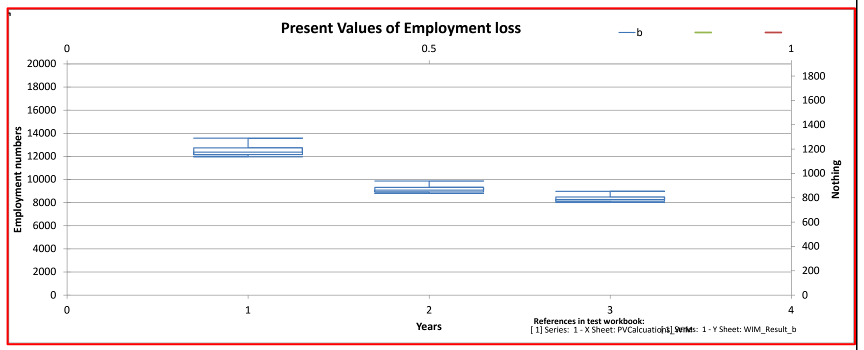
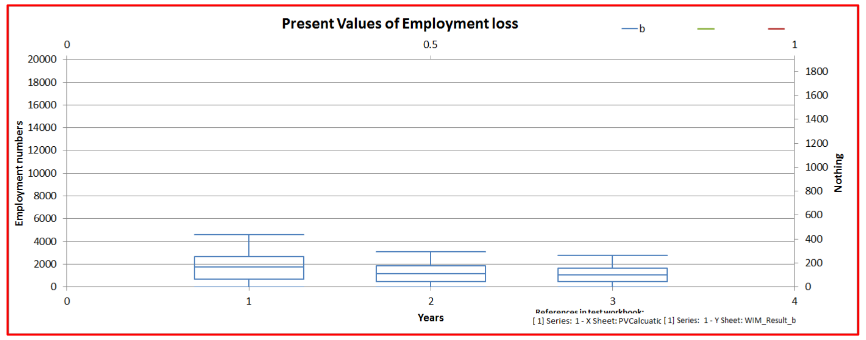
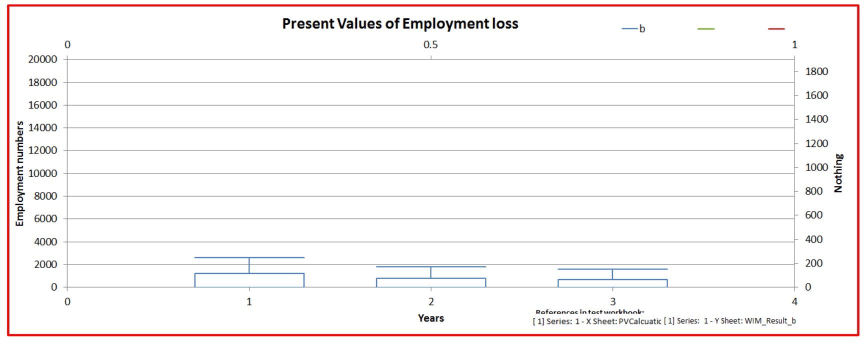
User Priority	Scenario 1 (100%–100%)	Scenario 2 (100%–60%)	Scenario 3 (90%–60%)
Original (call-for-licence study)			
Alternative			

Table 133: Present values of household income loss at 0%, 6% and 8%

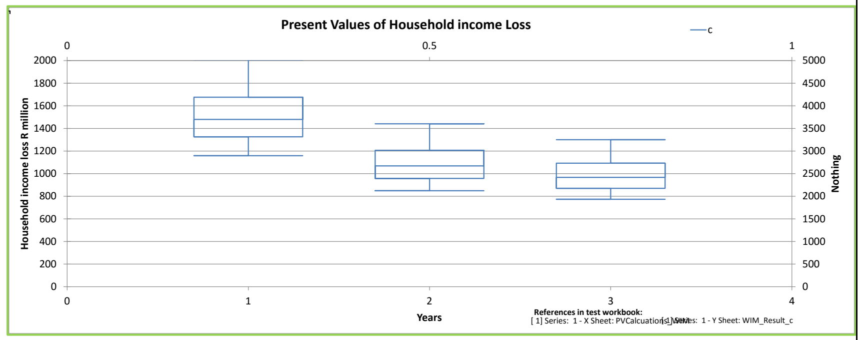
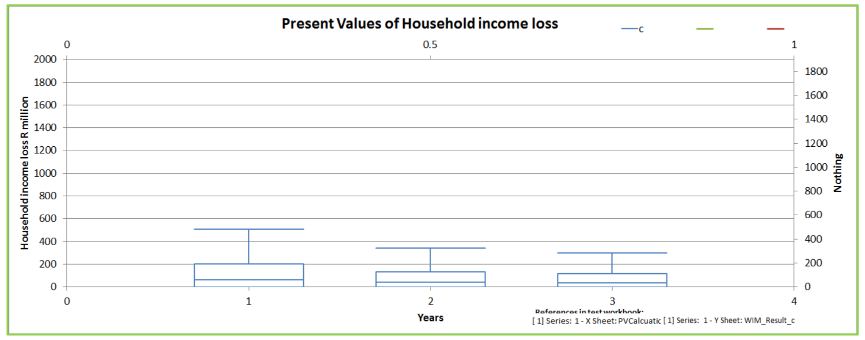
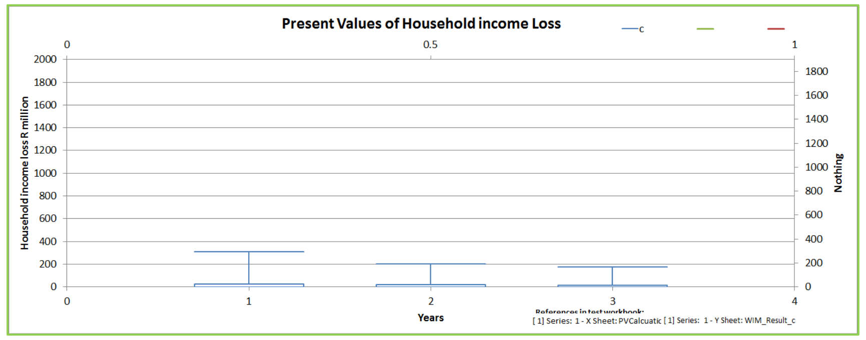
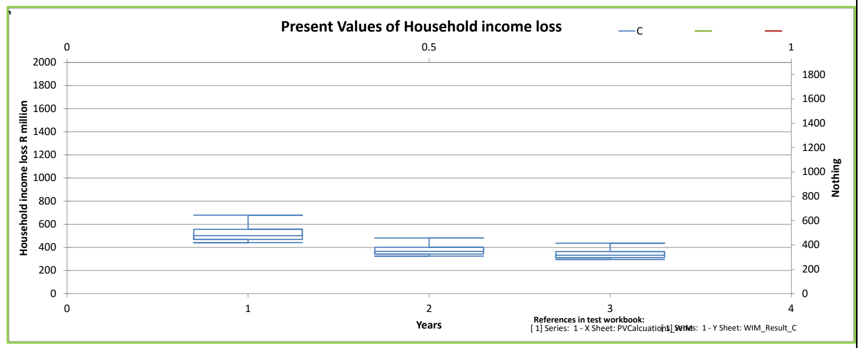
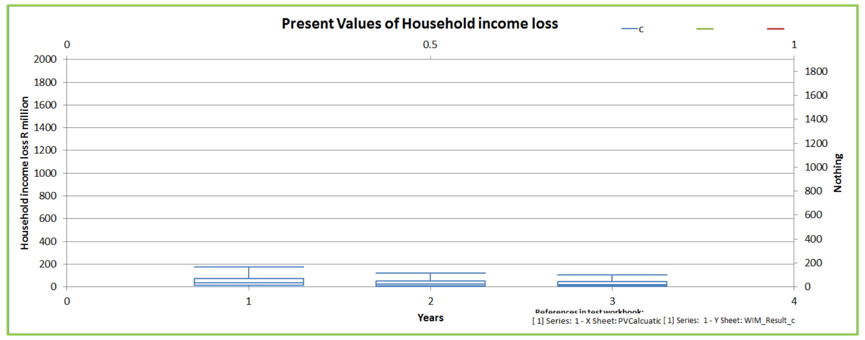
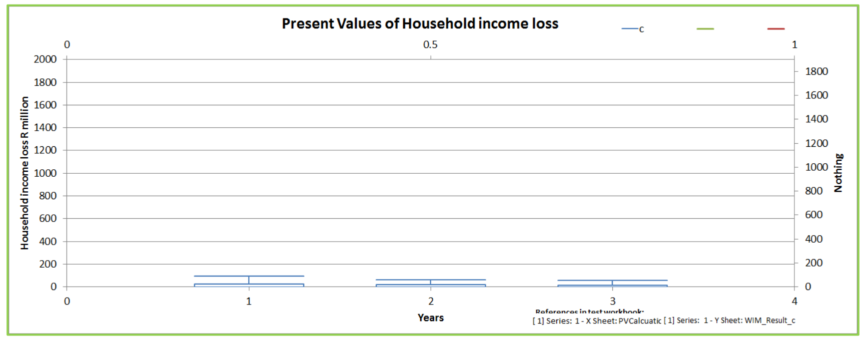
User Priority	Scenario 1 (100%–100%)	Scenario 2 (100%–60%)	Scenario 3 (90%–60%)
Original (call-for-licence study)			
Alternative			

Table 134: Annual values of GDP loss at 0%, 6% and 8

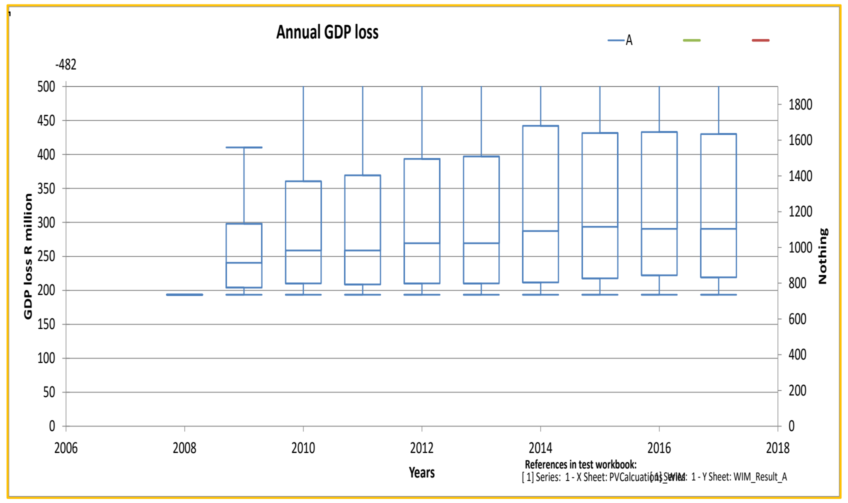
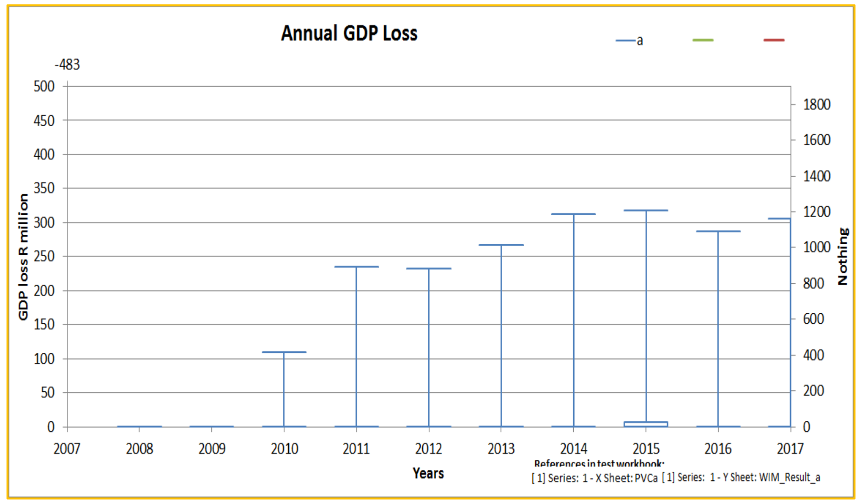
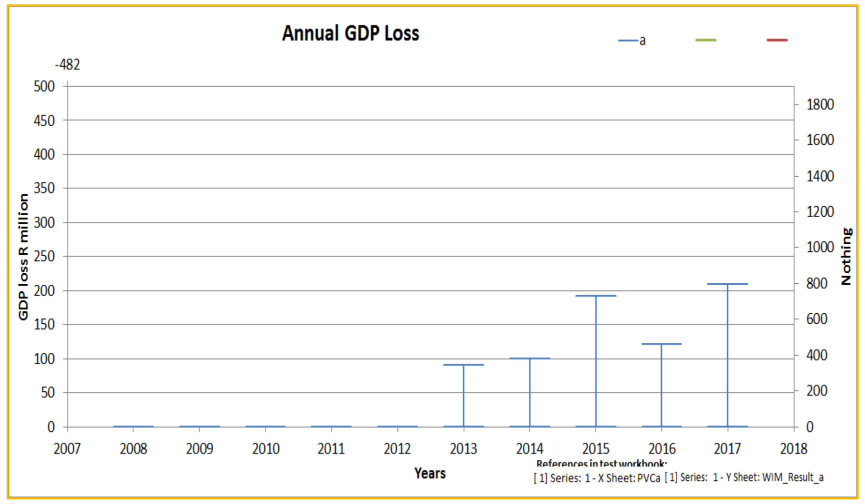
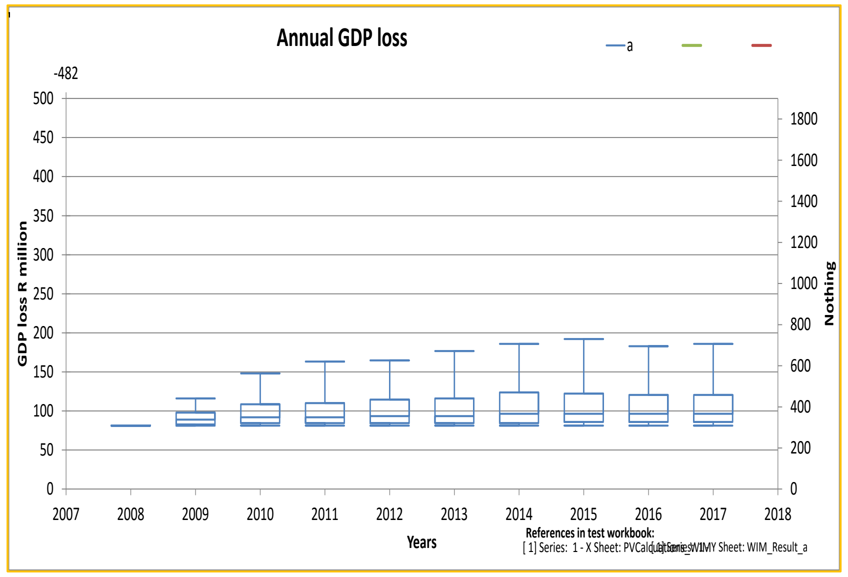
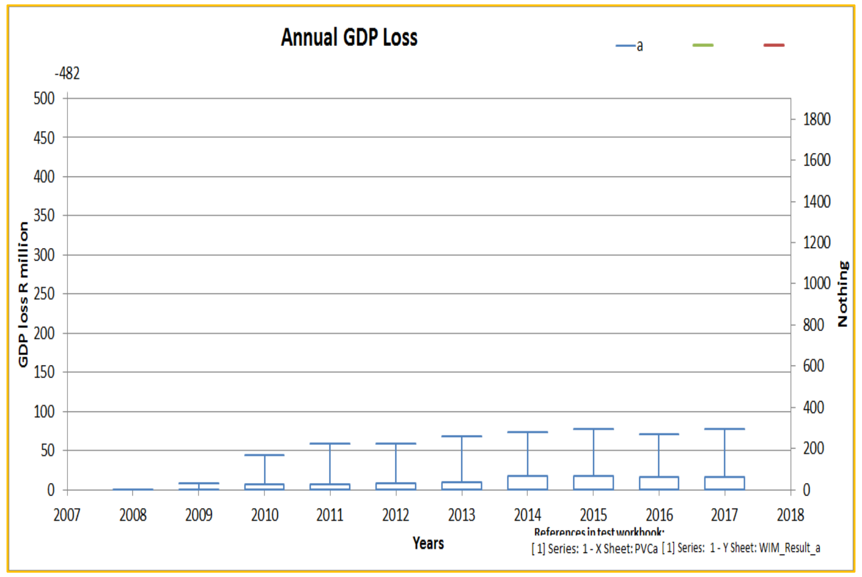
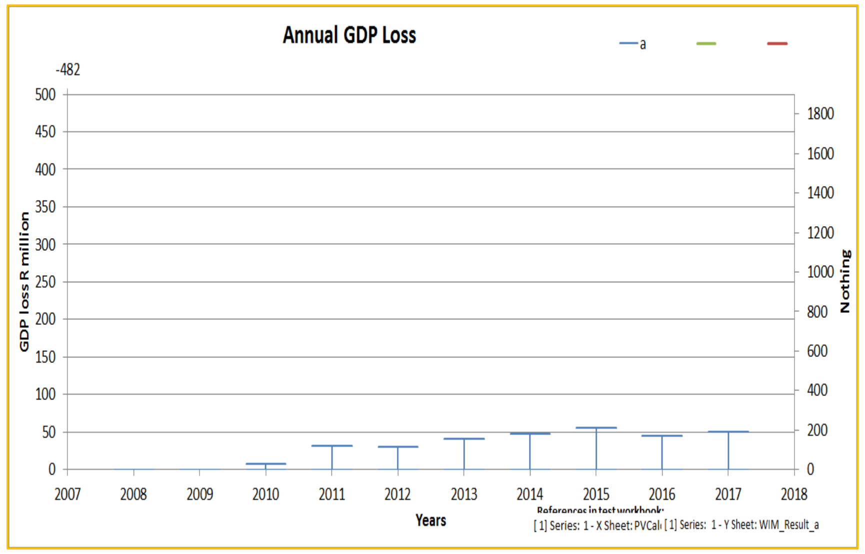
User Priority	Scenario 1 (100%–100%)	Scenario 2 (100%–60%)	Scenario 3 (90%–60%)
Original (call-for-licence study)			
Alternative			

Table 135: Annual values of employment loss at 0%, 6% and 8%

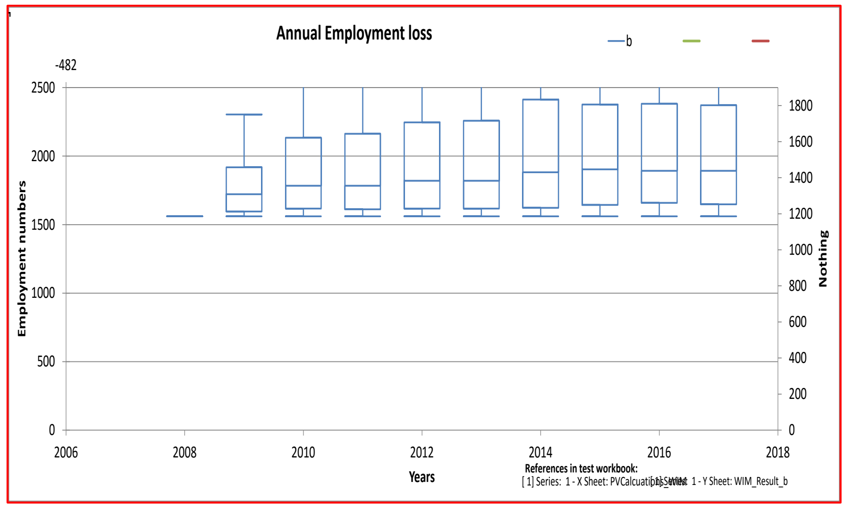
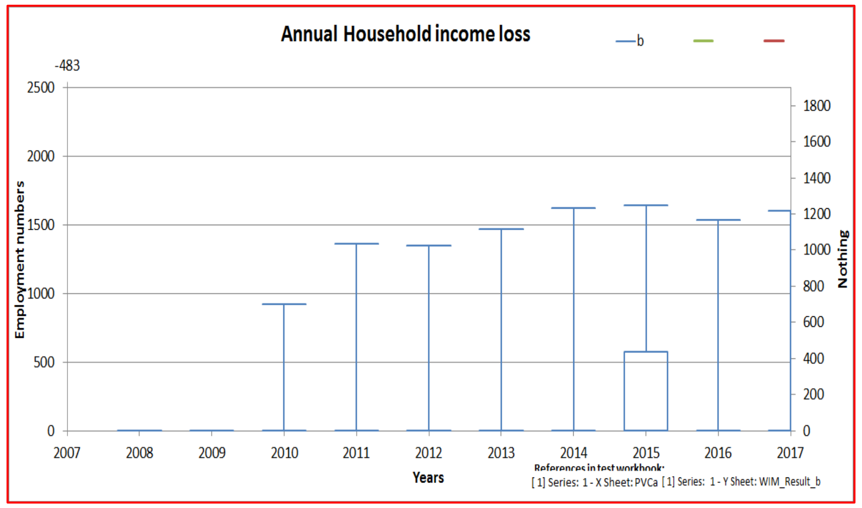
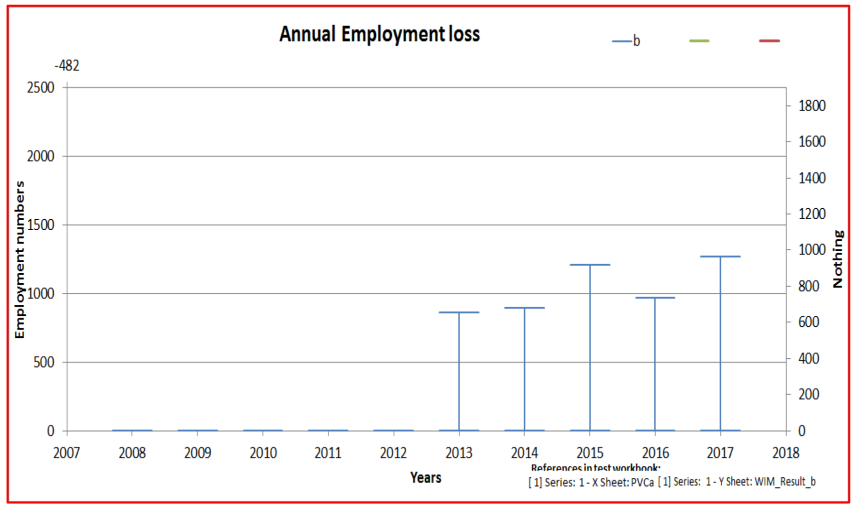
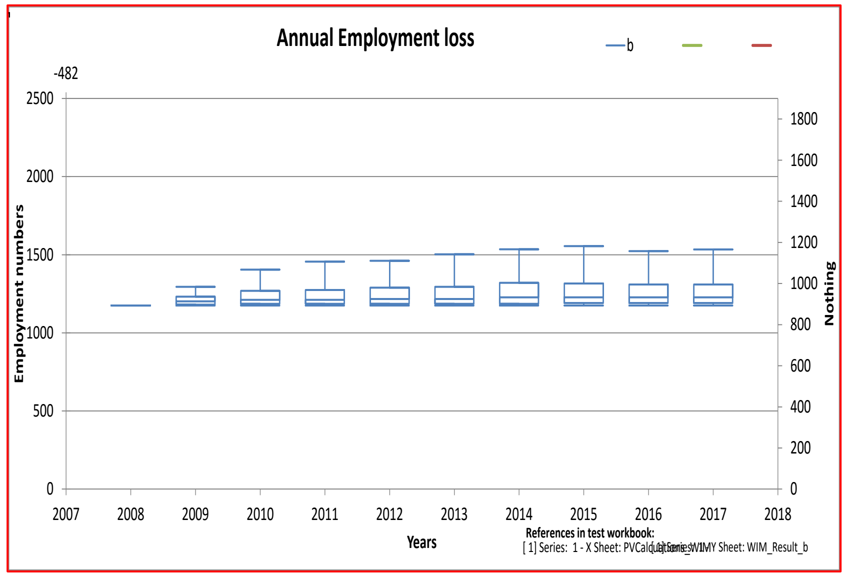
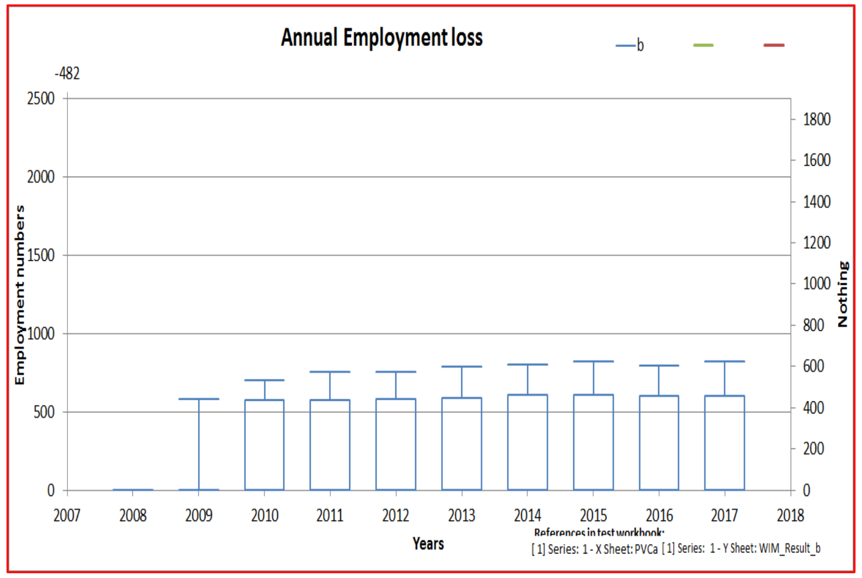
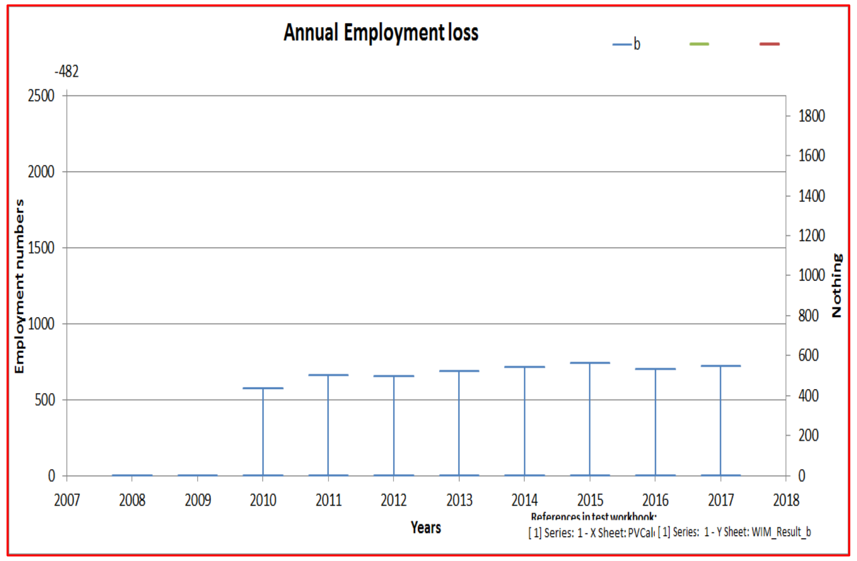
User Priority	Scenario 1 (100%–100%)	Scenario 2 (100%–60%)	Scenario 3 (90%–60%)
Original (call-for-licence study)			
Alternative			

Table 136: Annual values of household income loss at 0%, 6% and 8%

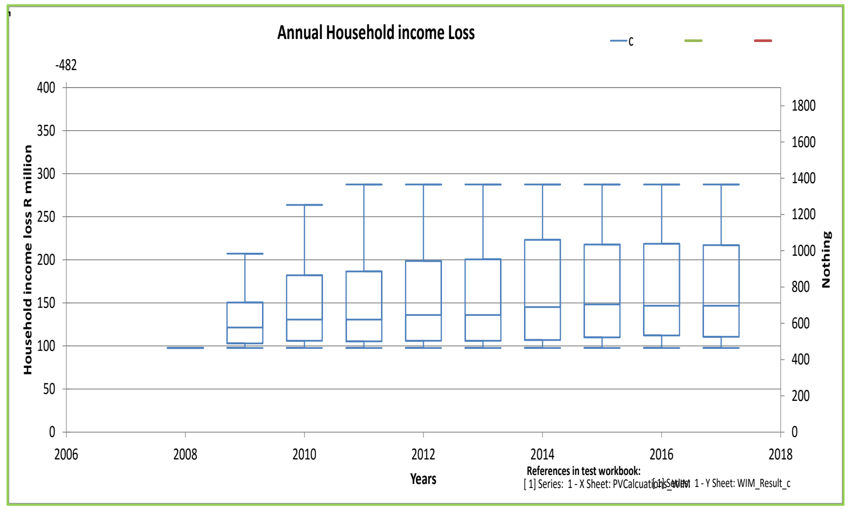
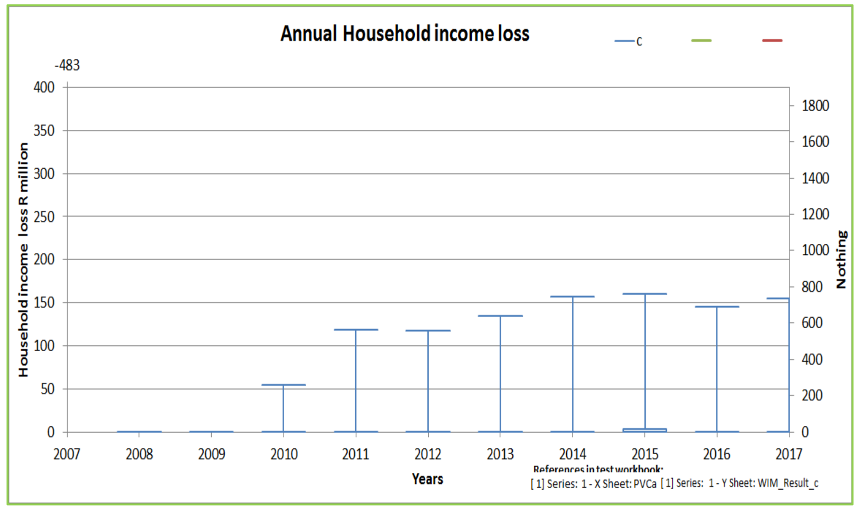
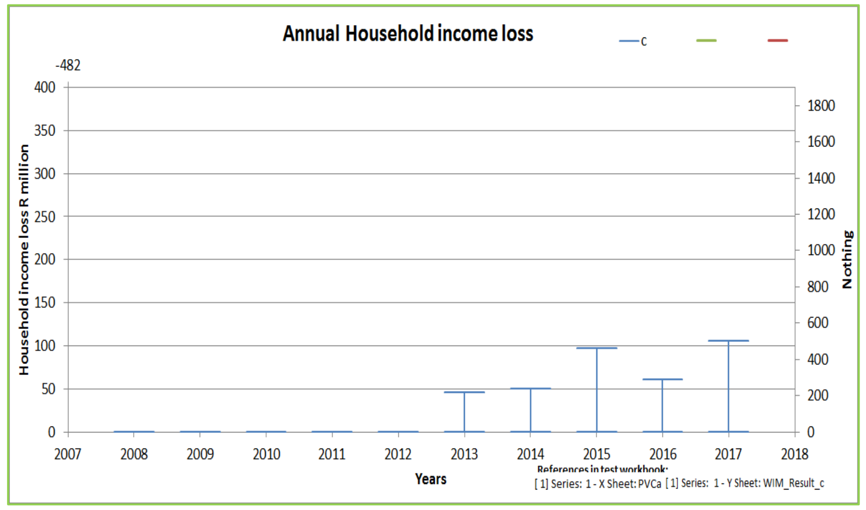
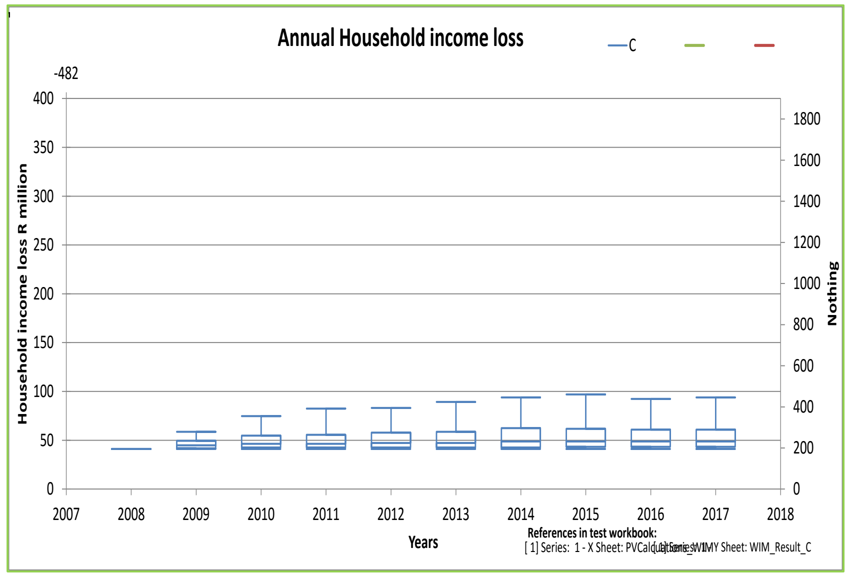
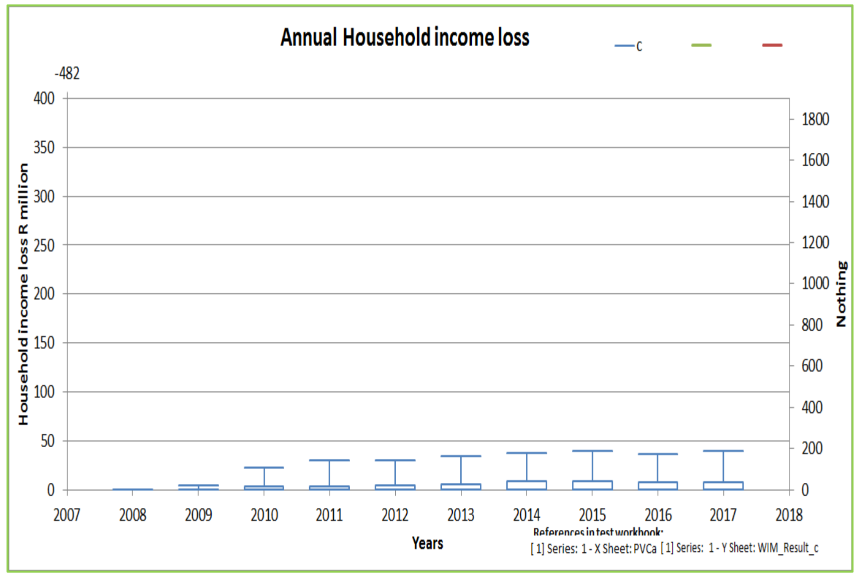
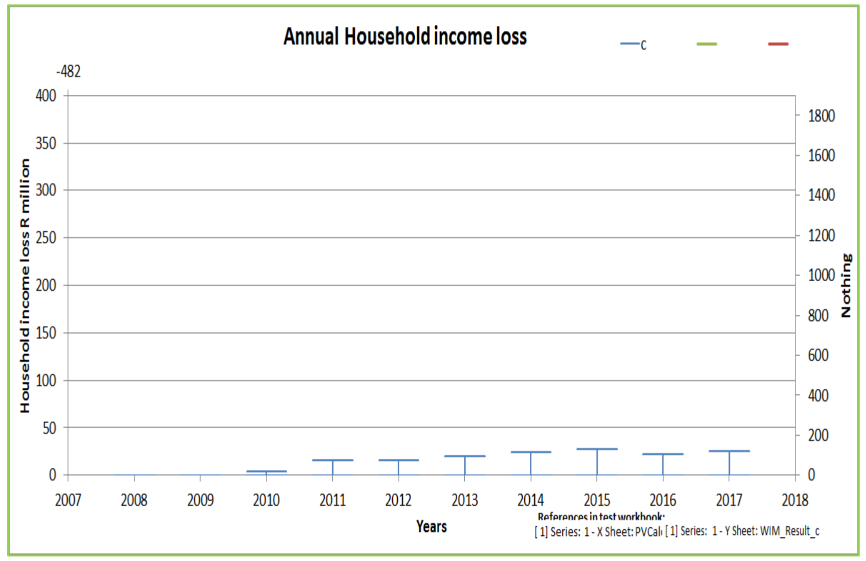
User Priority	Scenario 1 (100%–100%)	Scenario 2 (100%–60%)	Scenario 3 (90%–60%)
Original (call-for-licence study)			
Alternative			

Table 137 lists the results of the scenario analyses undertaken for the Mhlathuze System as a matrix between the scenarios analysed, the average present value, and the annual average of the three economic indicators. Table 137 shows that for scenarios where the alternative user priority classification was applied, the economic impact (in terms of loss in GDP, loss in household income and a reduction in employment numbers) was less than for the original user priority classification.

The alternative user priority classification applied entailed that 75% of the irrigation water requirement be supplied at an assurance of 98%, whereas 15% of the irrigation water requirement be supplied at an assurance of 95%, and 10% of the irrigation water requirement be supplied at an assurance of 75%. Even though this would mean a smaller initial curtailment of water supply to the irrigation sector, it might have a larger negative economic impact on the other user sectors considering the need for curtailments in the initial years of the analysis period.

Table 137: Mhlathuze System scenario-economic indicator matrix (present value and annual averages)

Scenario	GDP loss R million m³		Employment loss numbers		Household income loss R million m³	
	Present value	Annual	Present value	Annual	Present value	Annual
Scenario 1	3 012	301	19 296	1 930	1 521	152
Scenario 2	272	27	1 873	187	138	14
Scenario 3	98	9.8	608	61	50	5
Scenario 1a	1 040	104	12 532	1 253	525	52.5
Scenario 2a	107	11	1 874	187	54	5
Scenario 3a	40	4	674	67	20	2

It was decided in the *Modelling Support for Licensing Scenarios Study* that the Mhlathuze System should be operated in such a way that only 90% of the urban and 60% of the irrigation water requirements be supplied. However, by interpreting the results from the scenario analyses undertaken, it can be contemplated that the 90%–60% scenario (Scenario 3a) is the optimal option for the Mhlathuze System.

The results produced for Scenario 3 were in line with that of Scenario 3a except for a smaller loss in employment numbers. The reason for this comparison is to indicate that by implementing the alternate user priority classification, 100% of the urban allocation can be supplied instead of only 90%. However for Scenario 3a, system curtailments, and up to Level 2, might need to be implemented sooner than for Scenario 3, which means that water supply to urban users will be curtailed more severely. It is important that the economic impact of such curtailments be analysed before making a final decision on the user priority classification to be implemented.

6.3.3 Farm producer viability

Table 138 represents the viability results for the Mhlathuze River System at a water supply curtailment of 15%.

Main points from the analysis are:

- Only medium-term crops are affected when economic scenarios are included.
- Sugar cane is the prominent crop, which was evident in all the unviable results.

Table 138: Viability results for the Mhlathuze River System

<table>
<tr><td colspan="2">Water Supply: 15% Curtailment</td><td colspan="3">(30% | 3.3%)</td><td colspan="6">Small-scale Management Compensation Curtailed (30%,25%,35%|3.3%)</td><td colspan="6">Real Yield Curtailment (2.5%, 5.0%| 30%)</td><td colspan="3">(35% | 5%)</td></tr>
<tr><td colspan="2">Description</td><td colspan="3">Option 1: Most Likely</td><td colspan="3">Option 2</td><td colspan="3">Option 3</td><td colspan="3">Option 4</td><td colspan="3">Option 5</td><td colspan="3">Option 6: Extreme</td></tr>
<tr><td colspan="2">A) Management Compensation Deduct (%)</td><td>0%</td><td colspan="2">30%</td><td>0%</td><td colspan="2">25%</td><td>0%</td><td colspan="2">35%</td><td>0%</td><td colspan="2">30%</td><td>0%</td><td colspan="2">30%</td><td>0%</td><td colspan="2">35%</td></tr>
<tr><td colspan="2">B) Return on Capital: Real Yield Rate (%)</td><td colspan="9">3.32%</td><td colspan="3">2.50%</td><td colspan="6">5.0%</td></tr>
<tr><td colspan="2">Economical Scale</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td><td>L</td><td>M</td><td>S</td></tr>
<tr><td colspan="2">Number of Unviable Crops</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>1</td><td>-</td><td>1</td><td>1</td><td>-</td><td>1</td><td>1</td><td>-</td><td>1</td><td>1</td></tr>
<tr><td colspan="2">Unviable Crop Name</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>SC [1]</td><td></td><td>SC</td><td>SC</td><td></td><td>SC</td><td>SC</td><td></td><td>SC</td><td>SC</td></tr>
<tr><td rowspan="2">Short Term</td><td>Summer Vegetables</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Winter Vegetables</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Medium Term</td><td>Sugar Cane</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>X</td><td>-</td><td>X</td><td>X</td><td>-</td><td>X</td><td>X</td><td>-</td><td>X</td><td>X</td></tr>
<tr><td>Bananas</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Long Term</td><td>Citrus – Grapefruit</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

[1] Sugar Cane

Table 139 indicates the feasibility for crop production in the Mhlathuze River System at 15% and 40% water supply curtailments respectively for different farm unit sizes. The farm nett income reduces as the water supply curtailment to the system increases; however, the larger farms and medium-term crops tend to be affected least.

Table 139: Mhlathuze crop feasibility at 15% and 40% curtailment

Note: If Nett Income Negative, Not Feasible to Continue Production				**Curtailment 15%; Nett Income (R million)**					
				Option 1: Most Likely	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6: Extreme**
	Crop	**Farm Unit Size**	**Farm Size (Ha)**	**30% Fee, 3.3% Real Yield**	**25% Fee, 3.3% Real Yield**	**35% Fee, 3.3% Real Yield**	**30% Fee, 2.5% Real Yield**	**30% Fee, 5% Real Yield**	**35% Fee, 5% Real Yield**
Short term	Summer Vegetables	Large	50	R1.22	R1.22	R1.22	R1.26	R1.13	R1.13
		Medium	30	R0.54	R0.54	R0.54	R0.57	R0.49	R0.49
		Small	6	R0.06	R0.09	R0.04	R0.07	R0.05	R0.03
	Winter Vegetables	Large	50	R1.96	R1.96	R1.96	R2.00	R1.88	R1.88
		Medium	30	R0.99	R0.99	R0.99	R1.01	R0.94	R0.94
		Small	6	R0.15	R0.17	R0.13	R0.16	R0.14	R0.12
	Sugar Cane	Large	180	R0.37	R0.37	R0.37	R0.50	R0.10	R0.10
		Medium	120	R0.09	R0.09	R0.09	R0.17	−R0.09	−R0.09
		Small	35	R0.02	R0.05	−R0.00	R0.05	−R0.03	−R0.05
Medium term	Bananas	Large	80	R4.85	R4.85	R4.85	R4.94	R4.68	R4.68
		Medium	40	R2.19	R2.19	R2.19	R2.23	R2.11	R2.11
		Small	3	R0.06	R0.08	R0.04	R0.06	R0.05	R0.03
Long term	Citrus – Grapefruit	Large	80	R2.74	R2.74	R2.74	R2.84	R2.55	R2.55
		Medium	40	R1.14	R1.14	R1.14	R1.18	R1.04	R1.04
		Small	15	R0.46	R0.49	R0.44	R0.48	R0.42	R0.40
Note: If nett income negative,				Curtailment 40%; nett income (R million)					
Short term	Summer Vegetables	Large	50	R0.62	R0.62	R0.62	R0.66	R0.54	R0.54
		Medium	30	R0.18	R0.18	R0.18	R0.21	R0.13	R0.13
		Small	6	−R0.01	R0.01	−R0.03	−R0.01	−R0.02	−R0.04
	Winter Vegetables	Large	50	R1.13	R1.13	R1.13	R1.17	R1.05	R1.05
		Medium	30	R0.49	R0.49	R0.49	R0.51	R0.44	R0.44
		Small	6	R0.05	R0.07	R0.03	R0.06	R0.04	R0.02
	Sugar Cane	Large	180	−R0.22	−R0.22	−R0.22	−R0.09	−R0.48	−R0.48
		Medium	120	−R0.30	−R0.30	−R0.30	−R0.22	−R0.48	−R0.48
		Small	35	−R0.09	−R0.07	−R0.12	−R0.07	−R0.14	−R0.17
Medium term	Bananas	Large	80	R2.97	R2.97	R2.97	R3.05	R2.79	R2.79
		Medium	40	R1.25	R1.25	R1.25	R1.29	R1.16	R1.16
		Small	3	−R0.01	R0.01	−R0.04	−R0.01	−R0.02	−R0.04
Long term	Citrus – Grapefruit	Large	80	R1.37	R1.37	R1.37	R1.47	R1.17	R1.17
		Medium	40	R0.45	R0.45	R0.45	R0.50	R0.35	R0.35
		Small	15	R0.20	R0.23	R0.18	R0.22	R0.17	R0.14

7 DISCUSSION

The development of a new tool in this study, which was aimed at linking water resource models with an economic model, is considered to have been successful. The tool is referred to as the assurance of supply model (ASM). Existing data sets of the identified study areas, namely, the Orange River, Groot Letaba and Mhlathuze water resource systems were configured in the WRYM and WRPM and used accordingly for the scenario analyses. Sensitivity analyses were conducted to determine the behaviour of water resource systems under drought conditions and to evaluate the selected assurance of water supply criteria to the different water user sectors.

These analyses were further quantified by using the output from the water resource models as input to the economic model by an automated process to establish the socio-economic effects of the curtailment of water supply to the defined economic region. These regions were defined in the WIM based on the crops cultivated in sub-regional irrigation schemes within the three study areas. The economic model was updated accordingly for each economic region to reflect the economic impact that the water supply curtailments have on the crop production based on 2016 crop budget prices. The economic impact is expressed by means of a loss in GDP, loss in employment numbers, and loss in household income.

An important exercise entailed correlating the irrigation crop areas and volumes within irrigation schemes between the WRPM and the WIM. By using the ASM, simulated values were generated for the economic indicators over the analysis period applied in the water resource models and expressed as a single present value risk-weighted result.

The present value risk-weighted result per economic indicator was obtained by discounting the 1000 simulated values in each of the 10 years to a present value and attaining the average of the 1000 present values. The annual average is an average for all 1000 sequences for each of the 10 years; i.e. average of 10 000 simulated values. It is expected that the scenario with the lower results in terms of the loss in GDP, household income and employment numbers due to water supply curtailment will be the more favourable scenario to implement. However, it is possible that the storage projection plot for the specific system for the preferred scenario indicates a higher risk of failure of the system to supply the demand at the selected curtailment criteria. The user priority classification applied for the defined scenarios in the analyses undertaken using the WRPM and subsequently the proportion of curtailment of water supply to the irrigation sector was the only input variable to the ASM.

7.1 Economic Analyses

For the economic analyses executed in the WIM, the areas of land with various crop types under irrigation were identified and compiled per water supply system. These included all irrigation supplied with water from the resource (combination of dams) either via river or canal. The irrigation areas identified corresponded with the irrigation areas and volumes defined in the water resource models. Crop prices for 2016 were applied in the WIM and it was possible to generate economic outputs in terms of the loss in GDP, employment and household income per economic region should the water supply from the specific resource be curtailed.

In addition to this analysis process, crop production budgets were developed for short-, medium- and long-term crop life cycles expressed as weighted averages. For modelling purposes, inputs entailed the crop production budget, the economic farm unit size (large scale, medium scale and small scale), the level of water supply curtailment, and the water use (m^3/ha). The per hectare ratios were converted to farm unit sizes resulting in change in NFI, farm size unit (number of hectares) and in nett income to determine on-farm viability. The farm production model was designed to determine if the farmer would be able to continue farming on a sustainable level despite the curtailment in the water supply for irrigation of crops.

Table 140 summaries the viability results in the farm production model per economic region. The prices applied are those for 2016/2017. Where maize was used, the prices were 2015/2016 prices.

All hectares under irrigation are linear to the percentage water curtailment. The Great Fish River catchment in the Orange River System used to be part of the mixed-farm analysis due to its logistics and importance. In the Great Fish River catchment, the crop mix consists of various low-income crops compared to the Orange River System in total. This catchment also acts as a water transfer area. Having more than one water resource can provide water security for the downstream users, especially for the urban areas if water curtailments are initiated. The different crops comprising the so called mixed-farm of irrigated crops in the different study areas are indicated in Table 140.

The crop mix distribution in Table 140 identifies not only the different crops cultivated in the different areas but also whether they are short-, medium- or long-term crops. The feasibility analysis of water assurance levels applied is indicated in Table 141. From the analyses results it is clear that with the current crop mixes in the different study areas, farms will be feasible in most cases until a restriction level of 80%. On a 90% restriction level, the Great Fish River System will be the least feasible considering all the elements of production budgets. Groot Letaba was also non-feasible with the Mhlathuze standard farm still feasible, but this area would probably have started to consider management options as they were getting close to a non-feasible threshold for continuous production.

Table 140: Crop mix in the study areas

Life Cycle	Crops	Orange River–Fish River System	Groot Letaba System	Mhlathuze System
Short term	Maize	9.0%	0.0%	0.0%
	Soya beans	0.0%	0.0%	0.0%
	Dry beans	0.0%	0.0%	0.0%
	Industrial tomatoes	0.0%	0.0%	0.0%
	Fresh tomatoes	0.0%	0.0%	0.0%
	Potatoes	2.0%	0.0%	0.0%
	Summer vegetables	3.0%	5.9%	1.7%
	Winter vegetables	3.0%	5.0%	4.2%
	Wheat	0.0%	0.0%	0.0%
Medium term	Lucerne	82.0%	0.0%	0.0%
	Sugar cane	0.0%	0.0%	73.3%
	Bananas	0.0%	4.2%	2.5%
Long term	Grapes – fresh	0.0%	0.0%	0.0%
	Grapes – wine	0.0%	0.0%	0.0%
	Grapes – dry	0.0%	0.0%	0.0%
	Macadamias	0.0%	0.8%	0.0%
	Citrus – oranges	1.0%	37.8%	0.0%
	Citrus – grapefruit	0.0%	13.4%	18.3%
	Avocados	0.0%	19.3%	0.0%
	Litchis	0.0%	3.4%	0.0%
	Deciduous fruit	0.0%	0.0%	0.0%
	Palm dates	0.0%	0.0%	0.0%
	Mangoes	0.0%	10.1%	0.0%
	Total	**100%**	**100%**	**100%**

Table 141: Viability results in the farm production model of a standard farm

Water Supply Curtailment		Orange–Fish River		Groot Letaba		Mhlathuze Sc 1	
10%							
Change of NFI	i) % ii) R million	–11.8%	**–R 0.99**	–10.8%	**–R 2.00**	–10.3%	**–R 2.40**
Change on hectares	i) % ii) ha	–10.0%	**–30**	–10.0%	**–11.9**	–10.0%	**–12.0**
Nett income (profit/loss)	i) % ii) R million	–14.0%	**R 6.08**	–64.8%	**R 15.52**	–61.7%	**R 20.08**
Still feasible for producer	Yes/No		**Yes**		**Yes**		**Yes**
30%							
Change of NFI	i) % ii) R million	–35.5%	**–R 2.97**	–32.4%	**–R 6.00**	–30.8%	**–R 7.20**
Change on hectares	i) % ii) ha	–30.0%	**–90**	–30.0%	**–35.7**	–30.0%	**–36.0**
Nett income (profit/loss)	i) % ii) R million	–41.9%	**R 4.11**	–64.8%	**R 11.51**	–61.7%	**R 15.28**
Still feasible for producer	Yes/No		**Yes**		**Yes**		**Yes**
60%							
Change of NFI	i) % ii) R million	–70.9%	**–R 5.93**	–64.8%	**–R 12.01**	–61.7%	**–R 14.41**
Change on hectares	i) % ii) ha	–60.0%	**–180**	–60.0%	**–71.4**	–60.0%	**–72.0**
Nett income (profit/loss)	i) % ii) R million	–83.9%	**R 1.14**	–64.8%	**R 5.51**	–61.7%	**R 8.08**
Still feasible for producer	Yes/No		**Yes**		**Yes**		**Yes**
90%							
Change of NFI	i) % ii) R million	–106.4%	**–R 8.90**	–97.2%	**–R 18.01**	–92.5%	**–R 21.61**
Change on hectares	i) % ii) ha	–90.0%	**–270**	–90.0%	**–107.1**	–90.0%	**–108.0**
Nett income (profit/loss)	i) % ii) R million	–125.8%	**–R 1.82**	–102.8%	**–R 0.49**	–96.1%	**R 0.87**
Still feasible for producer	Yes/No		**No**		**No**		**Yes**

7.2 Water Resources

The cumulative volumes for each level of assurance of supply for the three different scenarios in the Orange River System are plotted on the short-term yield curve of the Orange River System when Polihali Dam is in place. Although impoundment of Polihali Dam is expected to only commence in 2022, if the user priority classification is to be amended, there needs to be provision for the worst case scenario and planned intervention. This is important for testing the viability of alternative user priority criteria. Considering that for all the scenarios plotted on Figure 83, restrictions are only required when the system storage is at 40% or less, the short-term yield reliability curves for the 40% starting storage was looked at in more detail as indicated in Figure 84. From these figures it can be seen that the risk criteria for Scenario 1 are violated.

It is important to bear in mind that the required curtailment calculated by the model is a curtailment on the nett requirement of the system. This is to account for the return flows in the system. In the case of Orange River, the return flows included in the allocation procedure or curtailment calculation were only those of the irrigation sector. Therefore, although the total requirement imposed on the system is 3426 million m³ as indicated in the user priority tables, the total nett requirement on the system is in the order of 3256 million m³.

During the 2016/2017 operating year, analysis results indicated that a 10% curtailment was required for the Orange River System. This meant that urban and industrial use would be restricted with 10% and the irrigation sector would be restricted with 15%. This system curtailment was on Level 1 where water was supplied at an assurance of 95% (risk of failure to supply of 1 in 20 years). However, the curtailments implemented in 2016/2017 were influenced by the total requirement from the system including the loss component of the water transferred from Gariep Dam to the Eastern Cape as well as an additional volume allowed for to be released into the Vanderkloof main canal (Scenario 3). The reason for allowing for 20% higher releases from Vanderkloof Dam to the Vanderkloof main canal in Scenario 3 was to provide for a possible worst case scenario. The actual releases during the 2015/2016 operating year were 20% higher than the planned target requirement due to unexpected high temperatures and low rainfall in the early summer.

Had one of the alternative user priority criteria in terms of assurance of supply been considered, the system might not have needed to be curtailed based on the given starting storage in May 2016. This means that if a larger volume of water was allocated to the level with an assurance of supply of 90% (risk of failure of 1 in 10 years) and an additional level of curtailment was introduced, a smaller volume of the system might have needed to be curtailed than with a volume prioritised at an assurance of supply of 95% (risk of failure of 1 in 20 years) and only three levels of curtailment. It is therefore advisable to establish at what risk criteria water should be supplied to the irrigation sector, or a certain part thereof, for the sector to remain viable during periods of drought.

One of the factors that can assist with such a decision is the percentage split between permanent and cash or annual crops cultivated within the specific water supply system. In terms of the crop mix cultivated in the Orange River System, 25% are permanent crops (e.g. citrus) and 75% are cash crops (vegetables, maize etc.). Ideally, water needs to be supplied to permanent crops at a higher assurance of supply since these crops produce over the long term whereas cash crops such as vegetables are seasonal and have life cycles as short as three months.

For the user priority classification used in Scenario 1, the average system curtailment required at an exceedance probability of 5% over 10 years is 0.659. This equates to 740 million m³ (22.7%) of the system yield, which is still a Level 1 curtailment. The average projected storage trajectory corresponding to this curtailment probability was at about 33% nett storage of the combined Gariep and Vanderkloof dams with a 95% exceedance probability.

Figure 84 shows that the 2600 million m³/a base yield line of the 40% short-term curve is in line with the storage of 33% projected at the 95% exceedance probability. An assurance of supply of 99% for the Scenario 1 user priority criteria is violated at this specific requirement.

If the requirement from the system is 2950 million m³/a at a system storage of 40%, then all requirement allocations need to remain below the base yield line. This means that for the user priority allocation criteria for Scenario 1, the base yield has been violated at the 99% (1 in 100-year risk) and 99.5% (1 in 200-year risk) assurance of supply.

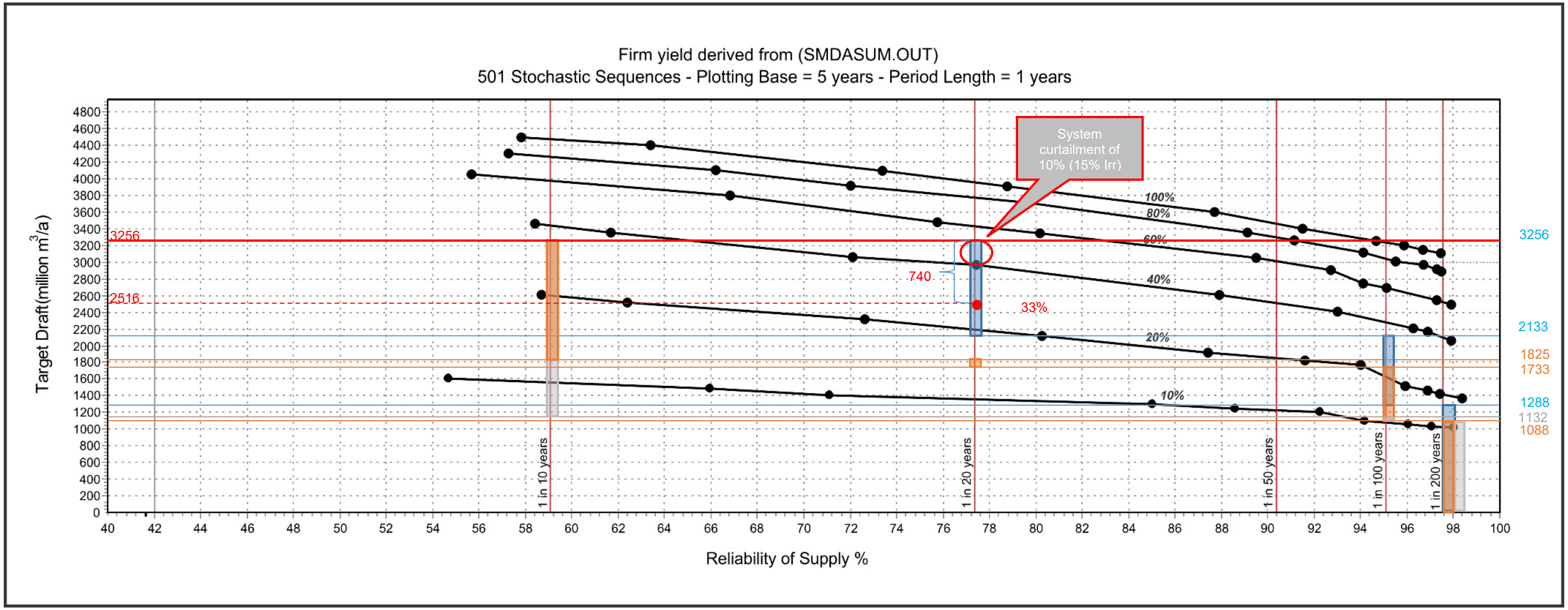


Figure 83: Orange River System short-term yield reliability curve with Polihali Dam

	Scenario 1	When system storage is below 60%, it will fail to supply the full requirement and use prioritised at a 1-in-20 year risk of failure will have to be restricted.
	Scenario 1a	When system storage is below 40%, it will fail to supply the full requirement and use prioritised at a 1-in-10 year risk of failure will have to be restricted. The use at a risk of failure of 1 in 100 years will need to be restricted before the dam reaches 20% storage. The remaining use at a risk of failure of 1-in-200 year will only need to be restricted once the system storage is 10% at which a system yield of 1000 million m³ is available at a 98% reliability of supply.
	Scenario 1b	When system storage is below 40%, it will fail to supply the full requirement and use prioritised at a 1-in-10 year risk of failure will have to be restricted. Use prioritised at a 1-in-100 year risk of failure will have to be restricted prior to the system reaching 10% at which point it only yields 1088 million m³.

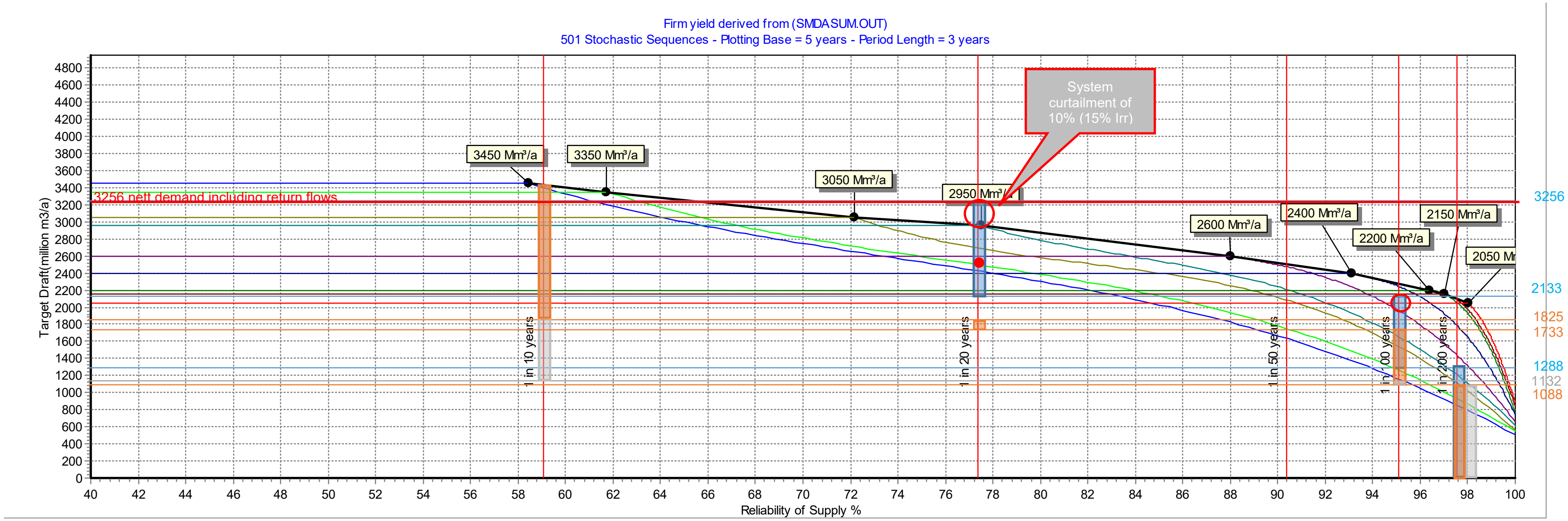


Figure 84: Orange River System 40% short-term yield reliability curve with Polihali Dam

7.3 Combined Analyses and Results

The aim of ASM was to link the output from the water resource models with that of the WIM to derive a relationship in terms of the economic impact of water supply curtailments per user priority criteria in a specific region and catchment area. Table 142 summarises the results for the nine scenarios analysed in the Orange River System per single weighted average given as the present value for 1000 simulations over 10 years as well as the annual average of the same values.

Table 142: Orange River System scenario-economic indicator matrix (present value and annual averages)

Scenario	GDP loss (R million m³)		Employment loss numbers		Household income loss (R million m³)	
	Present value	Annual	Present value	Annual	Present value	Annual
Scenario 1	7 430	743	66 843	8 684	3 109	311
Scenario 2	8 939	894	105 833	10 583	3 738	374
Scenario 3	10 645	1 065	137 211	13 721	4 438	444
Scenario 1a	5 185	519	57 965	5 797	2 171	217
Scenario 2a	6 318	632	72 010	7 201	2 643	264
Scenario 3a	6 674	667	75 244	7 524	2 793	279
Scenario 1b	3 586	359	40 065	4 006	1 535	154
Scenario 2b	4 383	438	49 988	4 999	1 872	187
Scenario 3b	4 656	466	52 697	5 270	1 993	199

These sets of economic and financial impacts show that farmers can continue farming with certain water supply curtailments and economic changes. However, if farmers have less land to maximise their production, farming businesses will be exposed easier to the risk of not being viable: both in the short term and long term. As the farming community provides numerous jobs for skilled, semi-skilled and unskilled workers, any extreme shock, especially an unforeseen condition, places immense pressure on farmers not only to continue farming, but also to prevent expansion of their production.

In events of viability risks, where farmers take a conservative approach by limiting expenses and expansion, it not only affects the farmers' own living standards and those who are employed by them, but also the local community. The reason for this is that profit and household income reduce, which result in a contraction in the broader economy as well. That implies that GDP consisting of salaries and wages, taxes and subsidies and gross operating surplus also reduces. As irrigation agriculture is in the primary sector, it affects secondary and tertiary sectors as well, which ultimately affect sustainment of jobs and socio-economic welfare of especially low-income households.

7.4 Other User Sectors

Although the focus of this research is mostly on the economic impact that water supply curtailments have on the irrigation sector, the allocation procedure prioritises other user sectors as well. Furthermore, the assurance of supply requirements among the different user sectors vary for the different scenarios analysed.

In the Orange River System, the irrigation sector is the predominant user of water at 64%. Losses are up to 24% but are not subject to water restrictions. It is assumed that the total volume allocated to losses will be released from the resource and are therefore categorised at the highest level of assurance of supply. The environmental requirements in the Orange River System are in the order of 8% and since it is part of the Reserve that needs to be supplied, it is unlikely to be subject to water supply curtailments. However, for the current operational scenario in the Orange River System, 32% of EWRs are allocated at an assurance of supply of 95%, which is within the Level 2 curtailment category. A total volume of

287.5 million m³ is released from the Orange River System for the Orange River mouth, which was documented by DWAF as long ago as 1996 during the ORRS. A classification study to obtain the final agreed EWR that needs to be imposed in the Orange River System is underway. Once this has been signed off by the DWS, the user priority classification will need to be reviewed and adjusted accordingly for the Reserve requirements to be adhered to.

The urban and mining sector is the smallest water user in the Orange River System and uses approximately 4% of the water. A portion of urban water use also forms part of the Reserve in terms of basic human need. It is important that any water supply curtailments in this sector will at least allow for the basic human need to be supplied. Any curtailments in this sector will start at garden irrigation, which does not contribute to the GDP or basic human need. However, it is such a small portion that it might be reallocated to a higher assurance of supply. Figure 85 indicates the percentage water use per sector in the Orange River System.

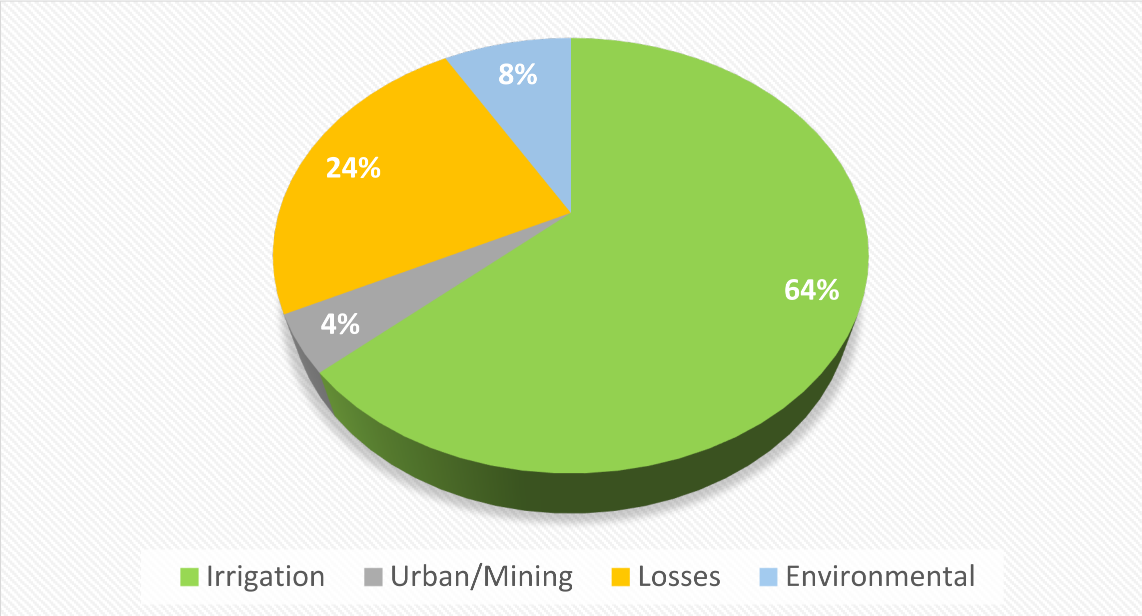


Figure 85: Water use per sector in the Orange River System

8 CONCLUSIONS AND RECOMMENDATIONS

To improve water resource management, this pilot study developed a tool to connect water resource models with the economic WIM currently used in South Africa. This tool will be applied to determine the optimal assurance of supply requirements during the decision process pertaining to risk-based drought restriction analyses.

The baseline of this study originated from the selected catchments – including the Orange River Water Supply System, the Groot Letaba River System and the Mhlathuze River System – of which previous studies' data and recommendations were incorporated.

Scenarios were identified that had been developed for these regions in previous studies and mentioned at the time to be investigated further. These studies included the:

- Development of Reconciliation Strategies for Large Bulk Water Systems: Orange River System.
- Integrated Vaal River System Annual Operating Analysis.
- Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System.
- Modelling Support for Licensing Scenarios Study for the Mhlathuze River System.

The development of the new decision support tool and the link between the water resource models and WIM were successful. It was expected that the scenarios rendering the lowest present values for the economic indicators would be more favourable. However, the storage of the systems as well as the viability of cultivation of various crops also need to be monitored should there be a sudden reduction in water supply.

Curtailment of water supply to the irrigation sector in the Orange River System was analysed for different assurance of supply requirement scenarios. Alternative options to the one currently in operation entailed supplying water to the irrigation sector or a part thereof at a lower assurance or higher risk of failure. In addition, parts of the urban and environmental sectors' water requirements were moved from a 95% to a 90% assurance of supply. Even though this rendered some positive results in terms of the economic impact water supply curtailments have on the irrigation sector by interpretation of the weighted average NPV per economic metric, other sectors such as the environment would be affected negatively.

During the actual drought in 2016, restrictions might not have been required had alternative assurance of supply criteria been applied. Therefore, it is recommended that further sensitivity analyses for the alternative scenario (User Priority B) be undertaken in future studies and investigated for implementation in the Orange River System.

In the Mhlathuze River System, the scenario applied for a call-for-licences and original priority classification (Scenario 3) seemed to have been favourable in terms of results, specific economic indicators, and the extent and timing of curtailments. It might be considered, however, that the permanent crops be prioritised at least at a higher assurance of supply considering that they are only 5.6% of all the crops cultivated.

A different approach was used for the Groot Letaba River System. Output files from WRYM – not WRPM – were incorporated in the new tool, which proved to work. This was a realistic approach to the economic analysis for the Groot Letaba River System, which is currently managed based on a dam-operating rule and not an allocation procedure. Additional scenario analyses for the Groot Letaba River System were not done at the time since the main focus was on establishing a link between the WRYM and WIM. The model is in place to make necessary amendments and do sensitivity analyses in future. It is recommended that irrigation users be approached, and that suggestions for an improved and optimal operating rule be made and tested with the new decision support tool.

Although the ASM has improved the process of determining assurance of supply requirements, final decisions pertaining to this matter still require expert discretion. In addition, the output from the ASM cannot solely be used to advise the user prioritisation, but needs to be interpreted in conjunction with the system yield reliability curves and storage projection plots and other users from the resource. It is important that the Reserve requirements be met at all times and that an optimum user priority option be obtained in order to exempt the Reserve requirements from water supply curtailments.

Furthermore, there is scope for model improvement to cater for other user sectors that also contribute to the specific catchment's economy. Such an improvement has commenced in other studies, namely, the Thukela–Vaal Transfer scenario analysis as part of the development of operating rules for the IVRS as well as for the development of operating rules for the LHWP Phase II.

In terms of the irrigation sector – and specifically the economic analysis thereof in the WIM – the crop's water requirements during its life cycle need to be revised to better reflect the impact of water supply curtailments on crop production. In the results obtained from the analyses undertaken, the relationship between the econometric losses and the volume of water curtailed generally had a linear form. When making water allocation decisions in times of limited water availability, it is important to ensure that crop water requirements during the critical crop-growing stages are fully met instead of distributing the allocation equally over the whole growing season.

The carry-over effect in terms of the economic impact of consecutive years of drought on the system has not been catered for. However, the crop production budget was set up and consulted outside the models used for analyses to determine the viability of farming subject to different water supply curtailments. Table 143 shows the viability results in the farm production model of a standard farm for the three study areas.

On a 90% restriction level, the Great Fish River System was the least feasible considering all the elements of a production budget. Groot Letaba was also non-feasible. The Mhlathuze standard farm was still feasible, but this area would probably have started to consider management options as they were getting close to a non-feasible threshold for continuous production.

Table 143: Viability results in the farm production model

Water Supply Curtailment		**Orange–Fish River**		**Groot Letaba**		**Mhlathuze Scenario 1**	
90%		**Standard farm**					
Change of NFI	i) % ii) R million	–106.4%	**–R 8.90**	–97.2%	**–R 18.01**	–92.5%	**–R 21.61**
Change on hectares	i) % ii) ha	–90.0%	**–270**	–90.0%	**–107.1**	–90.0%	**–108.0**
Nett income (profit/loss)	i) % ii) R million	–125.8%	**–R 1.82**	–102.8%	**–R 0.49**	–96.1%	**R 0.87**
Still feasible for producer	Yes/No		**No**		**No**		**Yes**

The main limitation to crop production budgets was that a representative budget structure for each crop and catchment was used. This included export price analysis that would affect the income of the life cycle of the crop. For further research projects, it is proposed to conduct more than just a desktop study to investigate each production structure of the different crops in depth, rather than just on a national level.

The new scientific approach to determine assurance of supply water requirements to be adopted from this study needs to be incorporated with the existing approaches; further development and refinement of the model are encouraged. Guidelines that can be used to assist water resource managers with the management and operation of water supply systems have been developed and are available in Volume 2 of this report.

Ultimately, the new tool serves to be an improvement to the Reservoir Monitoring Utility that has been applied in the IVRS Operating Analysis. In this study, the focus was to determine the economic impact resulting from of a reduction in water supply to the irrigation sector. It is recommended that the economic impact on other user sectors be studied more in depth as well. This should not have a significant impact on the decision pertaining to the assurance of supply requirements in the Orange River System since the irrigation sector uses up to 64% of the water and the urban sector only uses 4%. However, in the Groot Letaba and Mhlathuze river systems, the proportion of the urban/industrial sector to the irrigation sector is almost 50%. The modelling system should therefore be developed further to fit the detailed needs for future studies addressing the specified limitations in this research study. It will be advantageous to establish the economic impact resulting from a drought if no curtailments are imposed on the system.

It remains risky to prioritise 100% of the water requirements of irrigation agriculture (or any of the other user sectors) at a low assurance of supply. At least the percentage in line with the number of permanent crops cultivated in the region needs to be prioritised at a higher assurance of supply. Detailed research is therefore recommended to establish the economic impact and specifically loss resulting from a reduction in water supply to permanent crops. Additionally, it is recommended that more levels of curtailment be introduced in an allocation procedure. This can be done by the aid of plotting the water requirements of the different user sectors on the short- and/or long-term stochastic yield reliability curves of a resource in a specific water supply system. Furthermore, mixed crop farming is recommended – especially with large farming operations. This will ensure that the risk of water supply curtailments is not as concentrated on a specific crop type: the result is that farming would still be feasible. Entities such as AgriSA can be approached to help develop and define the risk criteria of water supply to the irrigation agriculture sector.

Although this study did not focus on the drought in the Western Cape, which was still experienced at the time of publishing, its various tools can be key components for preventative drought management on a macro and micro level.

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